PROCEEDINGS

of the

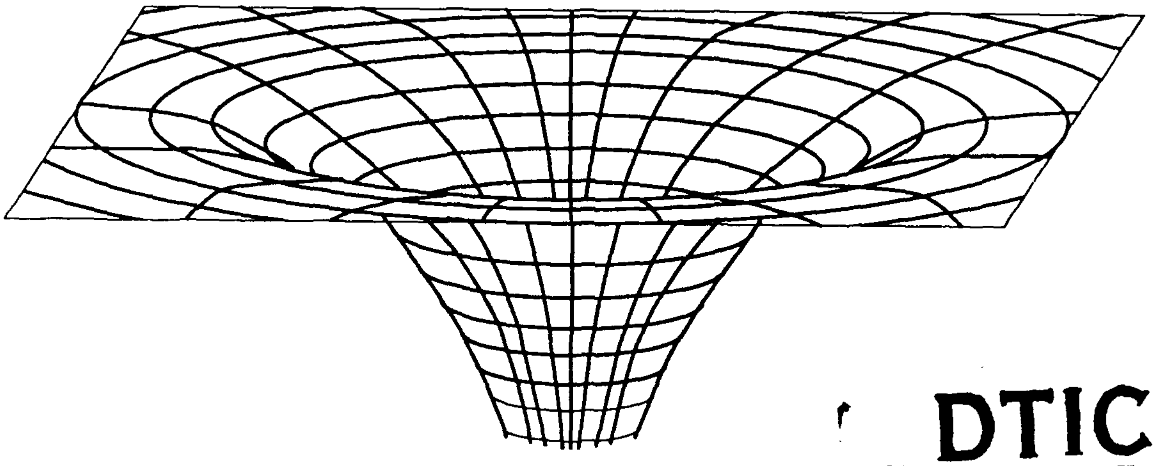
17th ANNUAL DAY OF SCIENTIFIC LECTURES

and

13th ANNUAL MEETING

of the

NATIONAL SOCIETY OF BLACK PHYSICISTS



March 21 - 24, 1990

at

SOUTHERN UNIVERSITY
BATON ROUGE, LA 70813

Sponsored by

LAWRENCE LIVERMORE NATIONAL LABORATORY

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Kennedy J. Reed, Editor

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The 13th Annual Meeting of the National Society of Black Physicists (NSBP) was held 21-24 March 1990 on the campus of Southern University in Baton Rouge, Louisiana. More than 200 individuals participated in the conference, including more than 80 graduate and undergraduate students. The conference included a memorial session in honor of a deceased past President, a distinguished banquet speaker, presentations for general scientific audiences as well as the core of scientific papers around the activities are typically organized. This document is a report on the papers presented.

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June 5, 1991

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Proceedings

of the

17th Annual Day of Scientific Lectures

and

13th Annual Meeting

of the

National Society of Black Physicists

Edited by

Kennedy J. Reed

The 1990 Annual Meeting was sponsored by Lawrence Livermore National Laboratory. Additional sponsors were the Office of Naval Research (ONR), the National Aeronautics and Space Administration (NASA), the National Society of Black Physicists (NSBP) and Southern University. The meeting was held on the campus of Southern University, Baton Rouge.

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FOREWORD

The 13th Annual Meeting of the National Society of Black Physicists (NSBP) was sponsored by Lawrence Livermore National Laboratory (LLNL) and held March 21-24, 1990 on the campus of Southern University in Baton Rouge, Louisiana. The annual meetings of the NSBP bring together scientists from universities, corporations and national laboratories. These meetings serve as a medium for net-working as well as for exchange of scientific information. They also provide an important forum for discussion and exploration of issues which impact the education of Black scientists and their roles in the scientific affairs of the nation. Students participating in these meetings have an opportunity to interact with professionals, and receive exposure to the current work of Black scientists around the country. The mentoring aspects of these meetings are especially important since we now face a growing national demand for trained scientific personnel, unfortunately concurrent with declining minority enrollment in educational programs which prepare students for careers in the physical sciences. With this in mind, we made a substantial effort to encourage student participation in the 1990 meeting. LLNL sponsored over 60 college and graduate students from all parts of the country and grants from the Office of Naval Research (ONR) and the National Aeronautics and Space Agency (NASA) helped to bring additional students to the conference. We tried to organize a program with relevance for students as well as professional scientists.

The conference opened with a memorial session in honor of Dr. Ernest Coleman who died January 17, 1990. Dr. Coleman who was a senior physicist in the Office of High Energy and Nuclear Physics of The Department of Energy (DOE) in Washington D.C., was president of NSBP from 1982-1984.

The scientific sessions included presentations by a number of noted scientists including Dr. Shirley Jackson of AT&T Bell Laboratory and Dr. James King, Deputy Assistant Laboratory Director for the Technical Divisions at the Jet Propulsion Laboratory. Professor Homer Neal, Chairman of the Physics Department at The University of Michigan, gave an update on the status of the Superconducting Super Collider, including a fascinating discussion of current elementary particle physics. Dr. Ronald Mallet of the University of Connecticut intrigued the audience with a presentation entitled "Evaporating Black Holes in an Inflationary Universe." One of the highlights of the conference was the keynote lecture by Dr. Julian Earls, Associate Director of NASA Lewis Research Center. Speaking in a packed auditorium, Dr. Earls, a marathon runner, compared the importance of training and discipline in preparing for a scientific career to the necessity of training and discipline in preparing for a marathon. At times the audience roared with laughter and at times they applauded in agreement, but mostly they listened in attentive silence during Dr. Earls' enlightening and inspiring address.

There were scientific presentations by undergraduate and graduate students, and sessions specifically aimed at encouraging students to continue working towards careers in science. Mr. James Evans, Assistant Associate Director at LLNL, discussed demographic changes in the coming decade and the challenges and opportunities they present for enhancing minority involvement in science. During a panel discussion on minority under-representation in science, a number of crucial issues confronting aspiring Black physicists were addressed by the panel and by the general audience as well. In a Saturday workshop, new funding initiatives were discussed, including the National Physical Science Consortium, a program which provides fellowships for women and minority students who want to pursue graduate studies in the physical sciences.

An international component of the conference was provided by the special guest speaker, Professor Francis Allotey, from the University of Science and Technology, Kumasi, Ghana - West Africa. Professor Allotey is also chairman of the African Association of Science. An additional international aspect of the meeting was shown in a luncheon talk given by Dr. Sekazi Mtingwa of Argonne National Laboratory. Dr. Mtingwa combined a technical talk with a slide presentation detailing his six-months as a visiting scientist in the USSR.

A number of students commented on the value of meeting minority physics students from areas of the country different from their own. There were students from such diverse locations as Stanford in California and Harvard in Massachusetts, as well as from a number of colleges and universities in the South and the Midwest. The interactions among the professionals were also beneficial.

More than 200 individuals participated in the conference. According to the Society's outgoing president, Professor Joseph Johnson of City University of New York, "The 1990 meeting was a quantum leap for NSBP meetings. Because of the quality of the program and the level of participation of students and professionals, a new era has been opened up for the National Society of Black Physicists."

It would be difficult to over-state the value of a conference like NSBP-90. Such conferences allow us to reach a significant number of students and to provide exposure, enrichment and support beyond anything available in a classroom. This type of nurturing could be an important factor in determining whether or not some students continue on in careers in scientific fields.

Kennedy J. Reed

ACKNOWLEDGEMENTS

The success of NSBP-90 was primarily the result of generous support from the AA/EEO Programs Division, and the Physics Department at Lawrence Livermore National Laboratory (LLNL). Support from the LLNL Physics Department allowed us to cover travel expenses for many of the speakers (including the keynote speaker, Dr. Julian Earls and the special guest speaker, Professor Allotey, who traveled to the conference from Ghana, West Africa). Publication of the Proceedings was also supported by the LLNL Physics Department. In particular, I would like to thank Dr. C. Bruce Tarter, Associate Director for Physics and Dr. Harold Graboske, Principal Deputy Associate Director for Physics, for their interest and support. Crucial secretarial support was provided through both the Physics Department and the AA/EEO Programs Division. The AA/EEO Programs Division also provided scholarships covering expenses for some of the graduate students attending the conference. I thank Ms. Karol Ruppenthal, AA/EEO Programs Division Leader, for her support.

A special acknowledgement is due Mr. Gerald Davis, Manager of the Historically Black Colleges and Universities (HBCU) Program at LLNL. Support enabling 54 students and 17 faculty members from historically Black colleges and universities to attend the conference was provided through the HBCU Program at LLNL. This unprecedented gesture and the enthusiasm and support of Mr. Davis were major factors in making NSBP-90 a memorable success.

We also gratefully acknowledge financial support from the Office of Naval Research (ONR) and the National Aeronautics and Space Administration (NASA).

I thank Southern University at Baton Rouge (SUBR) for hosting the conference, for use of the auditorium and luncheon facilities, and for assistance with registration. I also thank Dr. Dolores Spikes, Chancellor of SUBR, for her support and her welcoming remarks at the conference, and Dr. Rose Glee of SUBR for her encouragement.

We are indebted to many individuals at LLNL who helped with work on the conference, especially Ms. Joyce Doré and Ms. Betty Havill. The typing of dozens and dozens of letters and announcements, making travel arrangements for more than 80 participants from all parts of the country, and designing and printing the conference programs were part of the work contributed. The speakers were contacted and invited through LLNL, as were the session chairpersons and most of the panelists. The registration packets for the conference were assembled and shipped to Baton Rouge. These contributions are all the more noteworthy since many of these tasks were unexpected and were handled on a rushed basis.

I am grateful to Ms. Mary Yates and the Baton Rouge Area Convention and Visitors Bureau for invaluable information and assistance with arrangements in Baton Rouge, and also for their assistance with the conference registration.

Last, but by no means least, I would like to thank Ms. Donna McWilliams and Ms. Kathleen Telford of the LLNL Physics Department for their help with the difficult task of preparing the Proceedings for publication.

Kennedy J. Reed, Editor

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Tribute to Ernest Coleman

Homer A. Neal

University of Michigan
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Our dear colleague, Ernest Coleman, senior physicist in the Office of High Energy and Nuclear Physics of the U.S. Department of Energy in Washington DC, died on January 17, 1990.

Ernest was born on August 31, 1941 in Detroit, Michigan. He received his doctorate in physics in 1966 from the University of Michigan. He entered the University of Michigan graduate physics program in 1963, and received both his B.S. and M.S. in Physics during that year. He received his Ph.D. degree in August 1966, only three and a half years after entering graduate school. His Ph.D. thesis, "Proton-Deuteron Elastic Scattering at High Momentum Transfers", was completed under the direction of Professor Oliver E. Overseth. Following receipt of the doctorate he completed one year's postdoctoral training at DESY in Hamburg. Ernest was a gifted student and left Michigan full of promise for an outstanding career in physics.

Ernest's thesis experiment was a scintillation counter experiment at the Brookhaven Cosmotron studying backward pd elastic scattering. This was part of a program to study reactions that were candidates for a simple explanation via a one-nucleon exchange mechanism. The Overseth group had previously studied backward pp to d pi scattering, where the backward peaking was interpreted as due to one-neutron exchange. The group expected to find similar backward peaking in pd scattering. The group studied this reaction at energies of 1.0, 1.3 and 1.5 GeV. On the last day of the experiment a decision was made to do forward pd scattering at 2.0 GeV where previous data in the extreme forward direction existed. This measurement was trivial, rates were high, and the data came quickly, but they were not able to go very far forward since the experiment was not designed for this region and there was physical interference with an analyzing magnet. However, it was this data that was to become the most interesting part of Ernest's

experiment. His thesis results were published in PRL 16, 761, 1966 and in fuller form in PR 164, 1655, 1967.

Glauber theory for multiple scattering in nuclei had recently appeared and it was natural to apply it to the new forward pd elastic scattering data. Ernest got in touch with Glauber's former student who had worked with him on this theory, Victor Franco, then at Berkeley, and the two of them quickly published an application of Glauber theory to the data (PRL 17, 827, 1966). Their work gave a nice fit to the observed broad maximum due to the second scatter, but there was a clear disagreement with the most forward point or two, where Glauber theory would predict a strong dip due to destructive interference between the first and second scatter amplitudes, whereas there had been found a shoulder developing precisely where there should be a minimum. Further experimental verification of the shoulder was badly needed. In the following year a definitive Cosmotron experiment (Bennett et. al, PRL 19, 387, 1967) traced out the forward pd elastic scattering in detail, verifying the result that a shoulder existed where a dip was predicted. At the same time Coleman, in collaboration with the Michigan bubble chamber group, was analyzing pi d elastic scattering at 3.65 GeV/c from an exposure at the 20 inch deuteron bubble chamber at BNL and Coleman, Roe, Sinclair and van der Velde published their results (PRL 21, 187, 1968) which showed a good fit to Glauber theory but also in this case with a shoulder where a dip was predicted.

About this time Ernest left Michigan for a faculty position at Minnesota, where he was an associate professor of physics and served as special assistant to the university's Vice-President for Academic Affairs. Sometime in 1968 he realized that the D-state in the deuteron wave function, previously ignored, was an important ingredient in the Glauber model; it serves to fill in the dip, to give the experimentally observed shoulder in the interference region between single and double scattering. Although there is not much D-state in the deuteron wave function, its effects fall at just the right place, and it did not require much to fill the minimum. Coleman's contribution was never published, but was distributed to the world of Glauber theory enthusiasts and was widely referred to in the subsequent literature as "Coleman and Rhodes, private communication". About the same time, D. R. Harrington published the same explanation (PRL 21, 1496, 1968) and the two references were always cited together with Coleman's unpublished contribution fully acknowledged. At Minnesota he continued scattering experiments at the ZGS.

In 1974, Ernest accepted a two-year appointment to the Atomic Energy Commission's (AEC) Division of Physical Research as head of the Central Laboratory Research Section and accepted a second two year term under the Energy Research and Development Administration (ERDA), successor to AEC. He remained with the Office of High Energy and Nuclear Physics in ERDA's transition to the Department of Energy (DOE) where in 1980 he developed a unique and valuable paradigm based on extensive historical data to assist high energy laboratories project escalation costs. He interpreted research management policy, provided guidance to the laboratories and monitored progress on DOE university research grants in high energy physics.

Ernest's continuing interest in education, and in particular young people, was evidenced in his successfully proposing the Summer Science Program at the Stanford Linear Accelerator Laboratory (SLAC) that continues to the present day. He served as its Director from 1971-1984 while still meeting his obligations to his full time position with DOE. The Program nurtures scientific research capabilities of talented high school students aspiring to become scientists. Many of the participating students were members of minority groups sought out by Ernest.

His contributions to physics education were recognized by the American Association of Physics Teachers (AAPI) in awarding him the Distinguished Service Award in 1977.

He was a Fellow of the American Physical Society, a member of AAPT, the American Association for the Advancement of Science, American Association of University Professors, National Black Physicists Society, Blacks in Government, the European Physical Society, the German Physical Society and Phi Beta Kappa.

Ernest responded graciously to requests to address professional groups interested in affirmative action for women and minorities. His concern for improved opportunities for members of minority communities and his ever present willingness to assist them made him a highly sought after role model to address groups of young people and their mentors. The pressing need for increasing the participation of U.S. minorities in the sciences makes his death all the more unfortunate.

Now, for a few personal remarks. Ernest was a dear friend of long standing. We overlapped as students at the University of Michigan, working in the same general research area. And we continued to interact in the ensuing years. He was a person of great

intellectual ability, personal warmth, and extraordinary strengths in both experimental and theoretical physics. He later applied his considerable abilities in his career as an administrator. He will be sorely missed.

Ernest cared very much for the National Society of Black Physicists. I recall when he would often talk about plans for attending the next meeting, even though the date of the meeting might have been months away. It is a tribute to this organization that it is making a special effort at its 1990 meeting to honor the memory of Ernest Coleman. He was an inspiration to us all -- and the highest tribute we can pay to his memory is to redouble our efforts to uphold the standards of quality and the commitment to service that he so ably exemplified.

On behalf of Professor Overseth and the entire Michigan Department of Physics I wish to extend heartfelt condolences to Ernest's daughter, Jewel, who is with us today, and to his family and many friends.

The author is indebted to Professor Overseth of the University of Michigan Department of Physics and to Dr. Joseph Martinez of the Department of Energy for many of the details referenced above.

Dr. Dolores Spikes
Chancellor
Southern University
Baton Rouge

Dr. Shirley Jackson
AT&T Bell Laboratories

Opening Remarks

Jim Evans

Lawrence Livermore National Laboratory
Livermore, CA 94550

Good morning. On behalf of the National Society of Black Physicists, Southern University and A&M College, and the University of California Lawrence Livermore National Laboratory, it is my pleasure to welcome you to the 13th Annual Meeting of the National Society of Black Physicists. The management of the Lawrence Livermore National Laboratory is very pleased to co-sponsor this meeting with your host, Southern University and A&M College. Dr. Spikes and I recently met in Washington D.C. where she and the presidents from Jackson State University, Alabama A&M University, and Prairie View A&M University signed an agreement creating an alliance among the four schools that will thrust them to the forefront as they compete for contracts and grants. The Alliance will exchange the universities' ability to perform state-of-the-art research and produce world class scientists and engineers.

Enhancing the production of quality scientists and engineers is at the top of everyone's list; particularly the historically black colleges and universities (HBCUs). As most of you know, the National Science Foundation has predicted that by the year 2006 the Nation will be 750,000 scientists and engineers short. The United States Secretary of the Department of Energy, James Watkins, has directed each of the national laboratories to work with the Nation's educational community in an attempt to turn this situation around. It will not be easy. It is going to require cooperation between the various professional societies and educational institutions that is unprecedented.

The answer to the question of what is the U.S. to do if we wish to remain the world's leader in science and technology, is reap the harvest from fresh new minds that traditionally have not been tapped in great numbers. This new talent must come from the nation's people of color, white females, and the disabled. We must reap this talent in spite of dismal ACT examination scores. In 1986, for example, with an average score of 18.8, White and Asian Americans scored 19.7 and 19.6, respectively; Hispanic Americans of Mexican decent scored 15.2; American Indians scored 14.2; and Black Americans only

scored 13.0. The data for White and Asian Americans, when put into perspective with other leading countries in the world, offers no encouragement. In an international achievement test, the United States finished 32nd (out of 85) in geometry, 44th in algebra, and 25th in calculus. In science, the United States finished 13th (out of 13) in biology, 9th in physics, and 11th in chemistry according to the report published by the Task Force on Women, Minorities, and the Handicapped in Science and Technology titled "Changing America: The New Face of Science and Engineering."

The problem undergoes additional complexities as the brightest high school students elect to study non-science subjects. The attrition rate for Hispanic and Black students at the high school level offers very little opportunity for a significant increase in college science and engineering programs without the infusion of new ideas and programs to stimulate interest in academic achievement. For example, for every 100 Blacks who enter high school only 70% will graduate. Of those who do graduate 50% will be in a "slow" or remedial curriculum, and only 7% will be on a college prep track. Only 19% of those who graduate will make a "C" grade or better. In 1976, 33% of Black high school graduates went on to college. In 1986, that number had declined to 27%, according to the National Science Foundation.

In 1987, Hispanics received only 200 Ph.Ds in science and engineering. If the previously mentioned gap is to be filled, Hispanics will need to earn an estimated 2000 Ph.D.s per year throughout the nineties. White women received 1800 Ph.Ds in science and engineering in 1987. They will need to increase that number to 6000 per year. Blacks only received 100 science and engineering degrees in 1987. We will need to increase that number to 2000 per year. Currently, we make up 12% of the population but only hold 2% of the jobs in science and engineering. We must do better. One last set of statistics. In 1988, only 47 U.S. Blacks earned Ph.D.s in science and only 15 earned Ph.D.s in engineering. These are dismal numbers but the good news is that the HBCUs are doing their part. Most Blacks who earn graduate degrees did their undergraduate work at an HBCU.

I mentioned a few minutes ago the formation of the Science and Engineering Alliance. The Alliance is another example of universities being creative in an attempt to bridge the gap. The question before us today is what as Black physicists are you doing? What are you doing as individuals and what are you doing as an organization to promote science and engineering for our youth? I believe we have a unique opportunity to make things happen.

For example, the DOE Secretary James Watkins has essentially commanded all DOE Laboratories to work with local communities, colleges and universities to turn the educational crisis around. This means that resources that were previously dedicated to Programs will now be available for other purposes. I have personally attended meetings where he has stressed the importance of environmental integrity, scientific and engineering safety, and educational aggressiveness.

Almost everyone is saying we must train more women and minorities and most are willing to put their pocket books where their mouths are, but I am concerned that this opportunity will fade like a shadow in the night if we are not diligent in collecting the chips. First of all, there are those who refuse to believe there is, or will be, a shortage of scientists. For example, I refer you to the letter to the editor section of the March 5,1990 edition of the Chemical & Engineering News. There is a letter titled "Qualified Ph.D. Candidates" from a M. S. Lefar, Vice President of a chemical company in Newark called Epolin Inc. He claims that he receives dozens of unsolicited, highly qualified applicants from scientists each week. He mentions the number of scientists that have lost their jobs on more that one occasion. In other words, he is a non-believer. I know several managers and program leaders that even if they do believe, don't believe it will happen on their watch. They are still in the mode of using the good old boy system and it is still working for them. Also, don't forget the recent and current events that are occurring in Europe. It is just a matter of time until the discussion shifts to importing "more" Europeans to fill the scientific US gap. I give you one guess who the odd group out will be when that occurs.

Now, back to the National Society of Black Physicists. What can we do? I believe we need more National and State support but, as indicated, things seem to be loosening up. The fact of the matter is, it is time that we as Black scientists stop depending on the government or others to do something for us and accept the task of making things happen for ourselves. Dr. Walter Massey, Associate Director at the Argonne National Laboratory and Vice President of Research at the University of Chicago, who many of you know, at the 14th Annual National Meeting of the National Organization of Black Chemists and Chemical Engineers challenged the association to prepare our Black youth so that within five years we would have at least one Black student that would be among the finalists in the Westinghouse Science Talent Search. This year, in San Diego at our annual meeting, we will have our first national science bowl. This national science bowl will occur after the last two years of having regional and chapter science bowls. We believe by creating competition in a manner that is both educational and fun, we will encourage our top

students not only to pursue science but to excel in it. I offer the same challenge to the National Society of Black Physicists. I ask you to dedicate your organization to preparing a Westinghouse student or a supercomputer student. You may or not know that each summer one high school student from each state is brought to the Laboratory to work in the area of supercomputers. I am asking you to come out from behind the invisible wall that is often characterized by physicists. Physicists have had the public believing that the brilliance that begets physicists also makes them a bit eccentric and, unless talking with their peers, bashful and withdrawn. Many tend to shun recognition and refuse to be cast in the eye of the public. I am suggesting to you that we can no longer afford that behavior. Our children need to know you. They need to see you and touch you. They need to know that being a physicist is about hard work and not about genes that are only found in white parents. We need you to supplement, if not replace, the athlete as our role model. I will not even address the drug pusher and his pocket full of money. So I encourage you as an organization to set goals that will make a difference and I ask you as individuals to become involved and committed. Our children need you. We all need you. Congratulations on the beginning of your 13th Annual Meeting and thank you for inviting me.

Professor Loney Lewis
Jackson State University

BACK: Mr. James Evans, LLNL; Professor Ronald Mallett, University of Connecticut; Dr. Kennedy Reed, LLNL; Professor Joseph Johnson, CUNY; FRONT: Professor Francis Allotey, University of Science and Technology, Kamasi, Ghana; Professor C. H. Yang, Southern University

Professor Ronald Mallett
University of Connecticut

Evaporating Black Holes in an Inflationary Universe

Ronald L. Mallett

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Abstract

The past decade has seen the development of two theories that have drastically changed our notions about both black holes and the big bang model of the universe. One of these theories based on the work of Stephen Hawking of Cambridge shows that a black hole which represents the final stage of some stars may not last forever. They may actually evaporate. The other theory, due to investigations by Alan Guth of M.I.T., demonstrates that after the initial explosion of the universe called the big bang there was a state of extremely rapid expansion referred to as inflation. My research has been an attempt to connect these two theories.

Introduction

Of all the recent notions in physics and astronomy none has captured both the scientific and popular imagination quite like the concept of the black hole. This final state of stellar matter does indeed seem to be the stuff that science fantasy is made of. Nevertheless, the properties of black holes are rooted firmly in both classical as well as modern physics. Observationally there is very good reason to believe that these strange objects exist as a natural part of the cosmic environment. Current developments in quantum field theory appear to bring to light even more surprising features of the black hole suggesting that they may not last forever but evaporate under suitable conditions. This report will focus on the properties of both classical and quantum black holes. Understanding the genesis of quantum black holes will require an excursion into the inflationary universe. Finally, it is suggested that a new phenomenon child universes - may be detected by means of micro-black holes.

Classical Black Holes

It is now known that a black hole can be formed by the collapse of any star that has a mass exceeding two and a half solar masses. During its stable phase a star is maintained in a state of hydrostatic equilibrium against gravitational collapse by internal radiation pressure. The equation governing this process being given by

$$\frac{dP}{dr} = -\frac{GM(r)\rho}{r^2} \tag{1}$$

where P is the radiation pressure, M(r) is the mass in a sphere of radius r and ρ is the density at r. When the star has exhausted its nuclear fuel it begins to collapse. The effect of this collapse can be understood by examining the change in the escape velocity of an object near the surface of the star. The standard equation of energy conservation in classical mechanics is of the form

$$\frac{1}{2} mv^2 = \frac{G M m}{r} \tag{2}$$

Eq. (2) yields the usual result for the escape velocity from an object of mass M given by

$$v = \sqrt{\frac{2 G M}{r}} \tag{3}$$

Consider e.g., a star of ten solar masses with a radius of 3×10^6 km then the escape velocity is about 6.65×10^7 cm/s. Assuming that the mass remains fairly constant then as the star collapses the escape velocity escalates until at a radius of about 29.5 km the escape velocity equals that of the speed of light. After this point light itself can no longer escape from the star and the star appears as a spherical black hole in space (Fig. 1). Substituting v = C in Eq. (3) implies that the radius of any object that becomes a black hole is given by

$$R_s = \frac{2 G M}{c^2} \tag{4}$$

The best observational evidence for the existence of a black hole comes from a x-ray source called Cygnus X-1 in a spectroscopic binary that is at a distance of about 10,000 light years. The visible star associated with this binary is a hot, blue giant star. It has been determined that this star is being orbited by an invisible companion that has a mass greater than eight solar masses and can only be detected due to the infalling matter ejected by the visible star. The x-rays are emitted from an accretion disk just outside the black hole.

The preceding discussion would seem to indicate that Newton's theory of gravity is sufficient for a discussion of black holes. This, however, is not the case. There are serious problems with Newton's theory that come to light when account is taken of Einstein's special theory to relativity. It is a fundamental feature of Einstein's special theory that the propagation of physical effects is limited by the velocity of light. According to Newton's theory the effects of gravity propagate instantaneously at a distance. In order to resolve this difficulty Einstein was led to develop his general theory of relativity. In this theory gravity is considered as a property of space and time due to the presence of matter. The effect of matter on spacetime can be characterized by the change in the distance between two nearby points. The Pythagorean theorem implies that for two nearby points in a flat two dimensional plane the distance is given by

$$ds^2 = dx^2 + dy^2 \tag{5}$$

In the special theory of relativity Eq. (5) can be generalized at once for the distance between two nearby points in flat four dimensional spacetime. The analogous equation is given by

$$ds^2 = c^2dt^2 - dx^2 - dy^2 - dz^2 \tag{6}$$

In spherical coordinates Eq. (6) has the form

$$ds^2 = c^2dt^2 - dr^2 - r^2d\theta^2 - r^2\sin^2\theta d\phi^2 \tag{7}$$

General relativity requires that the presence of an object of mass M modify the distance between two nearby points such that Eq. (7) now acquires the form

$$ds^2 = c^2\left(1 - \frac{2GM}{c^2r}\right)dt^2 - \frac{dr^2}{\left(1 - \frac{2GM}{c^2r}\right)} - r^2\left(d\theta^2 + \sin^2\theta d\phi^2\right) \tag{8}$$

This modification manifests itself as the presence of a gravitational field. The curvature of spacetime by matter may be visualized in terms of a rubber sheet representing spacetime and a steel ball representing matter. It is clear that the presence of the ball curves the sheet with the result that anything moving on the sheet is affected by the presence of the ball (Fig. 2). One of the most important predictions of the general theory was that light from a distant star would have its path deflected by the curved space near the sun (Fig. 3). This prediction was verified by Eddington in 1919. Another more recent verification has come from the delay of radar signals emitted by the Viking satellite as it passed by the sun (Fig. 4). Einstein's theory also resolves the original difficulty associated with Newton's theory in that gravitational influences must now propagate in the form of gravity waves at the speed of light.

The existence of black holes within the framework of the general theory can be seen by examining the so-called Schwarzschild line element in Eq. (8). At a fixed point $dr = d\theta = d\phi = O$ and Eq. (8) reduces to

$$ds^2 = c^2\left(1 - \frac{2GM}{c^2r}\right)dt^2 \tag{9}$$

Eq. (9) can be rewritten as

$$dt^2 = \frac{d\tau^2}{\left(1 - \frac{2GM}{c^2r}\right)} \tag{10}$$

In Eq. (10), $d\tau = ds/c$, can be viewed as the time of an observer at rest near the surface of the star. This time is also called the proper time. The time dt in Eq. (10) is that measured by a distant observer. Eq. (10) implies that as the star collapses with $r \rightarrow 2\ GM/c^2$ then $dt \rightarrow \infty$. This means that a light signal emitted near the surface of the star appears to take forever to reach a distant observer. In effect, the external observer never sees the light and concludes that the star has become a black hole at a radius of $r_s = 2\ GM/c^2$. It should be noted that this is the same result that was obtained in Eq. (4) from very different

considerations. r_S is called the Schwarzschild radius and is a measure of the size of the black hole. This parameter also determines the location of the event horizon of the black hole. Nothing can be known by an external observer of events taking place at distances less than r_S. The black hole can be thought as the extreme curvature of spacetime (Fig. 5). The picture of the black hole just discussed is still incomplete in that it does not take into account the quantum mechanical nature of matter. This is considered next.

Quantum Black Holes

Quantum field theory leads to a modified view of the vacuum of spacetime due to the time-energy uncertainty principle which has the form

$$\Delta E \, \Delta t \geq h \tag{11}$$

Eq. (11) implies the existence of virtual particle-antiparticle pair creation for a period of time $\Delta t \sim h/\Delta E \sim h/2\,mc^2$ within a distance $\Delta x \sim c\Delta t \sim h/2\,mc$ (Fig. 6). This phenomenon is known as vacuum polarization. In 1975, Stephen Hawking[1] showed that these vacuum fluctuations were modified by the presence of a black hole. In the Hawking process one particle of the pair may fall down the hole while the other escapes. The net flux of particles and antiparticles at infinity appear to come from the black hole (Fig. 7). The net result is a thermal particle production by a black hole at a temperature given by

$$T = \left(\frac{h\,c^3}{8\pi^2 kG} \right) \frac{1}{M} \tag{12}$$

where M is the mass of the black hole. Eq. (12) implies that the black hole gets hotter as the mass decreases. The time of evaporation $t \sim 10^{71}\,(M/M_\odot)^3$s where $M_\odot$ is a solar mass. A black hole of mass $M \sim 10^{15}$ gm would evaporate in 10^{10} years which is about the age of the universe. Black holes of this mass have a Schwarzschild radius of $r_s \sim 10^{-13}$ cm. Such objects could not have been produced by normal stellar evolution. This implies that attention should be focused on primordial black holes that were produced at the beginning of the universe.

Evaporating Black Holes and the Inflationary Universe

Current results in elementary particle physics have led to profound changes in the standard model of the early universe known as the big bang. It is believed that the present state of the universe with its four basic forces is the result of a much more symmetric phase of the universe in which three of the forces were combined. The model describing this early state of affairs is called the grand unified theory (GUT). According to this model at a time about 10^{-35} seconds after the Big Bang, which occurred between 15 - 20 billion years ago, the universe cooled to a temperature of 10^{14} GeV and underwent a phase transition (Fig. 8). Alan Guth[2] put forward the theory that during this transition the universe underwent a state of extreme expansion now known as inflation. This inflationary stage of the universe solved a number of longstanding cosmological problems. However, since Hawking evaporating black holes should have been produced in the very early universe the question arises as to the effect of inflation on these primordial black holes. A model of the interaction between the universe and these black holes was developed by the present author[3] based on an exact solution of the Einstein gravitational field equations for a radiating mass imbedded in an expanding universe. The line element has the form

$$ds^2 = \left[\frac{\dot{M}}{\Phi(M)}\right]^2 \left[1 - \frac{2M(r,t)}{r} - \alpha^2 r^2\right] dt^2 -$$

$$\left[1 - \frac{2M(r,t)}{r} - \alpha^2 r^2\right]^{-1} d\tau^2 - r^2 \left(d\theta^2 + \sin^2\theta d\phi^2\right) \tag{13}$$

$$\Phi(M) = M' \left[1 - \frac{2M(r,t)}{r} - \alpha^2 r^2\right] \tag{14}$$

with $\dot{M} = \partial M(r,t)/\partial t$, $M' = \partial M(r,t)\partial r$. The cosmological constant λ is given in terms of α of by $\lambda = 3\alpha^2$. It is found that the effect of inflation is to decrease the black hole evaporation and thereby increase the lifetime.

In more recent work Guth[4] proposed that under certain conditions a whole new universe may form inside a black hole (Fig. 9). This new universe has been called a child universe. The present author is currently[5] investigating the problem of detecting the formation of these child universes using the new solution of Einstein's field equations in Eq. (13). It is felt that the genesis and evolution of a child universe within a Hawking black hole should produce a characteristic change in the radiation rate. Thus it may become possible to actually observe the creation of a new universe.

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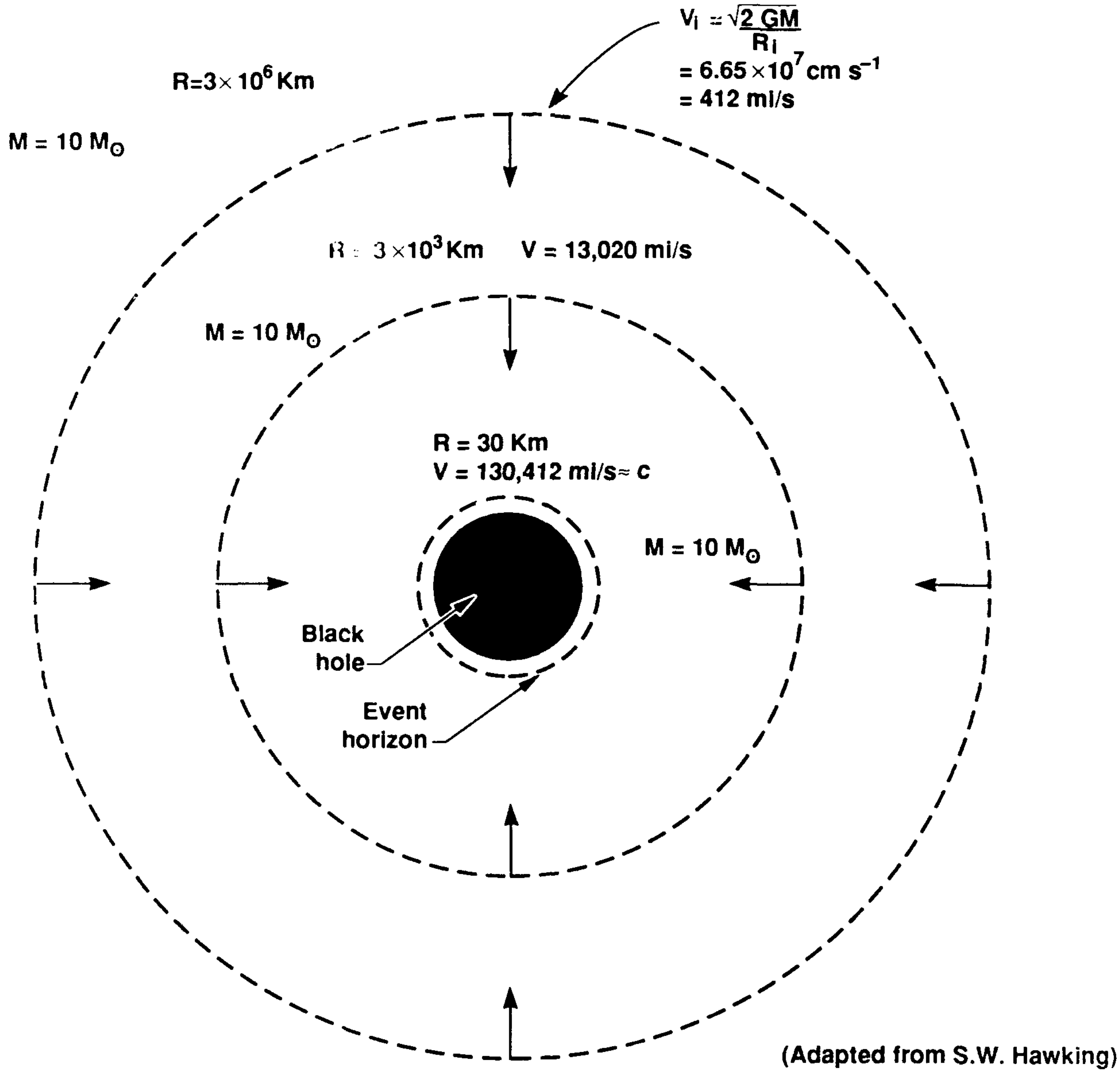
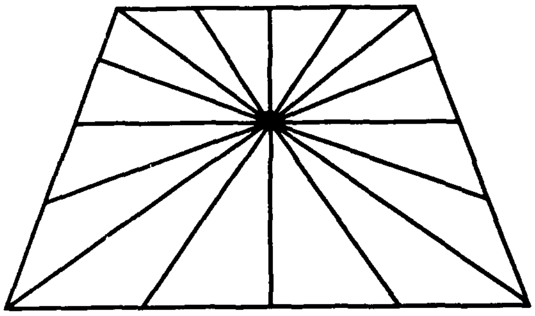
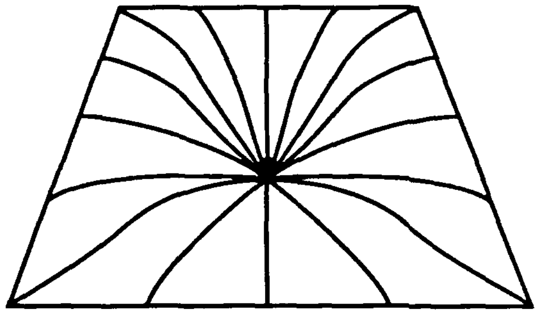


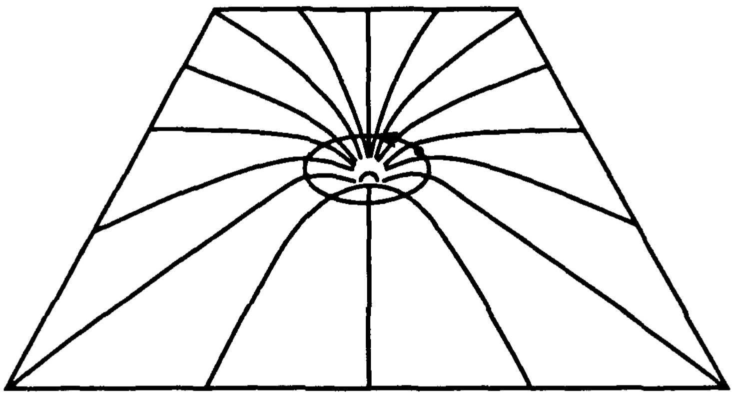
Fig. 1. Death of a star escape velocity and the black hole



Empty space

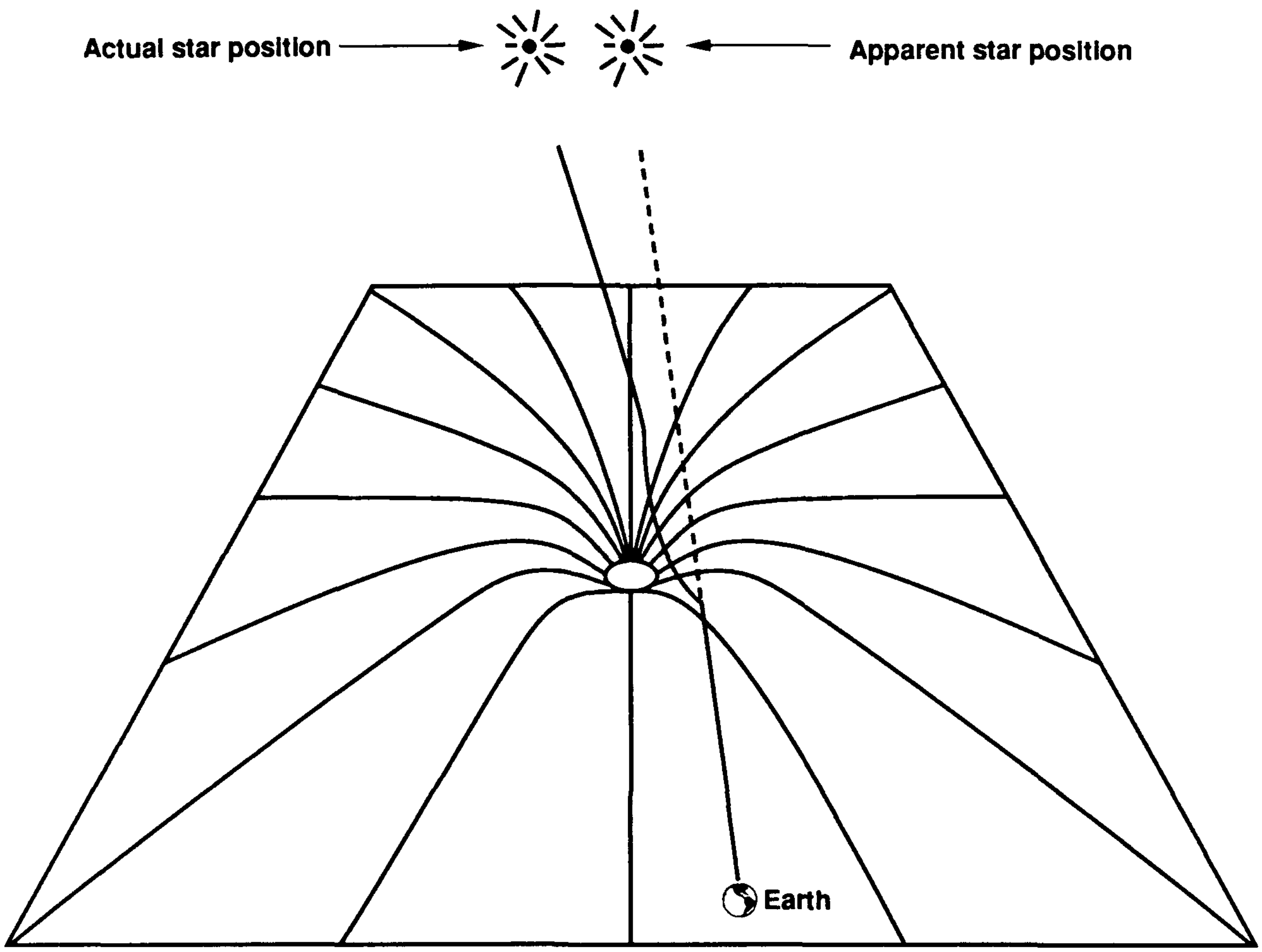


Space with a mass point in it



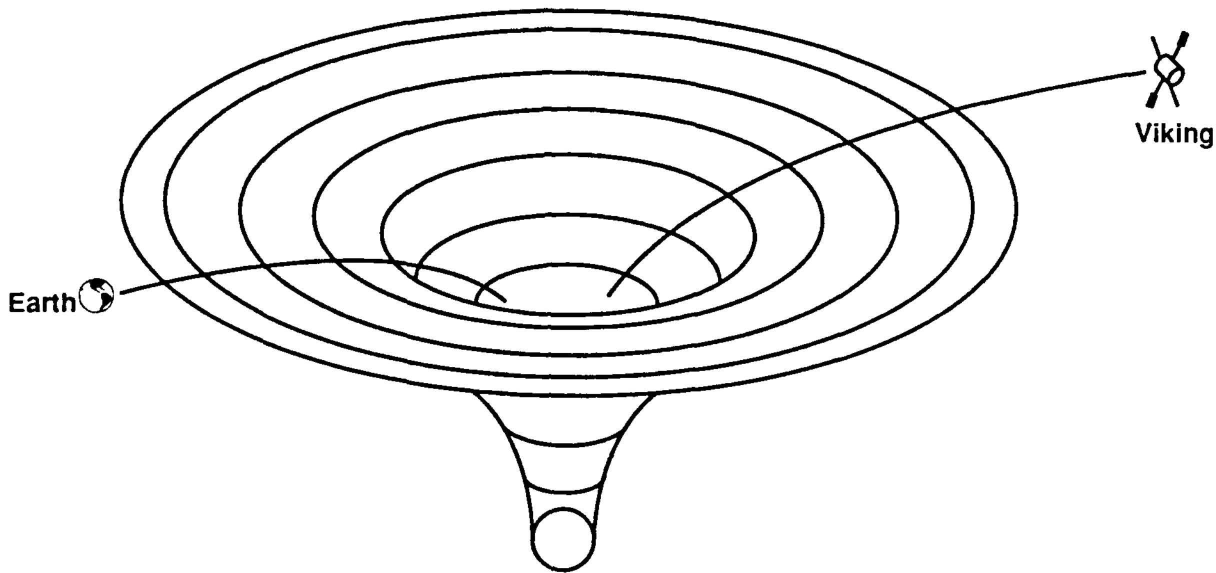
A planet Moves around the sun nearly uniformly partway down in the warp in space that is caused by the sun's mass.

Fig. 2. Matter curves space



Light from a distant star has its path altered as it dips down into the curved space near the sun

Fig. 3. Bending of light



Abell/Morrison/Wolff

Fig. 4. Time delay of radar signals

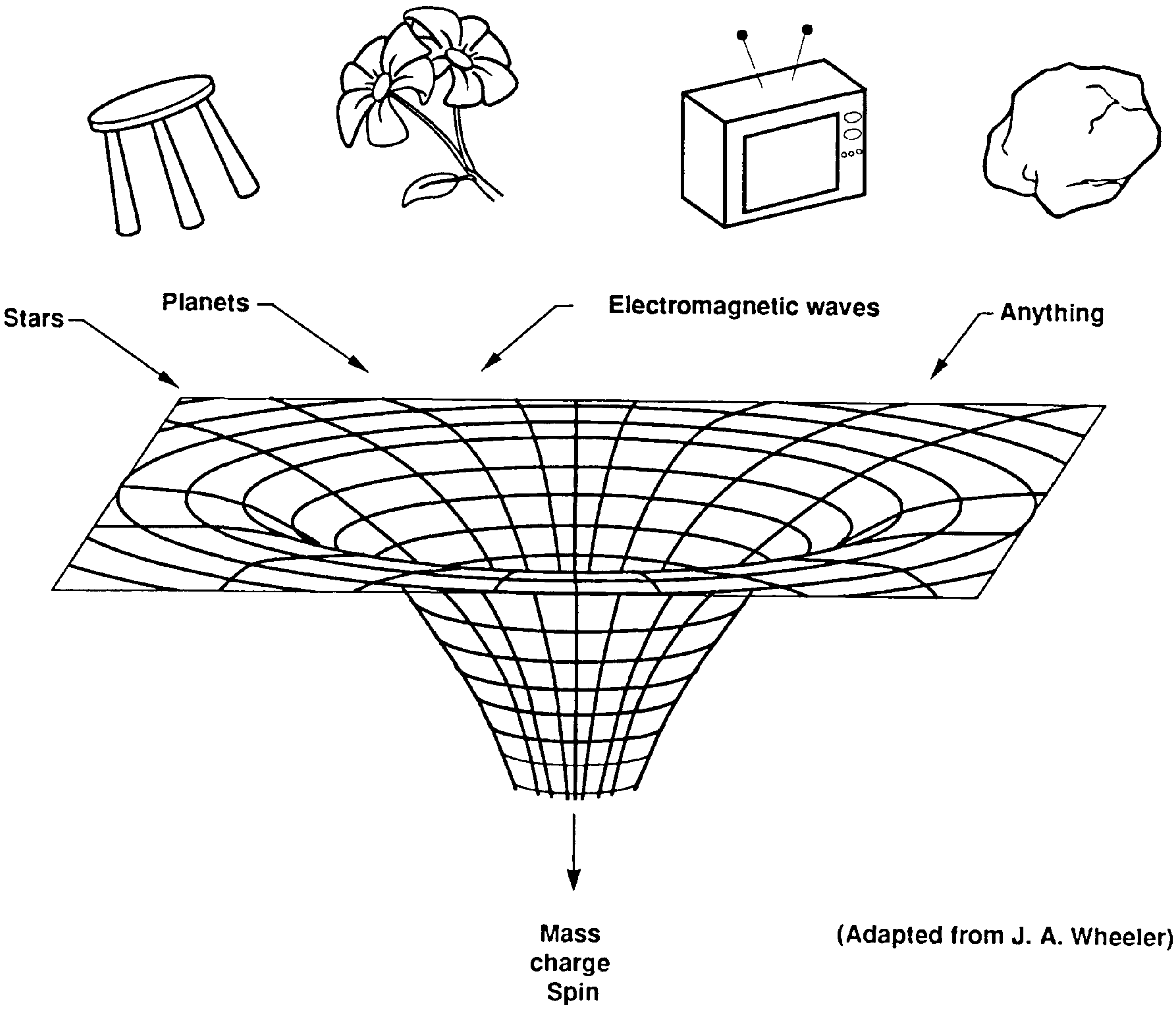
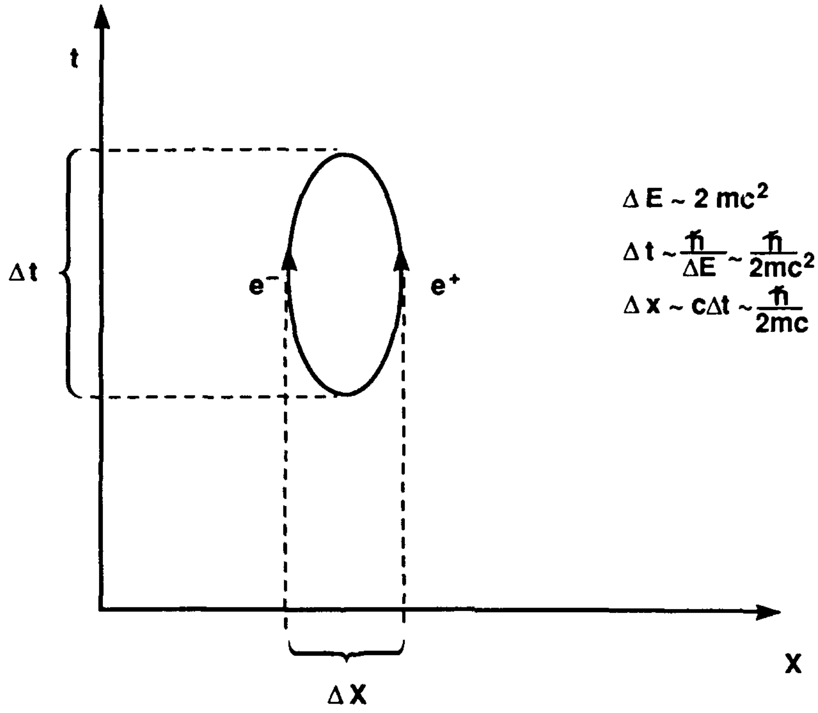


Fig. 5. Black hole in action

Time energy uncertainty principle

$$\Delta E \Delta t \geq \hbar$$

Virtual particle - antiparticle pair creation for a period of time ~ Δt within a distance ~Δx



$$\Delta E \sim 2\,mc^2$$

$$\Delta t \sim \frac{\hbar}{\Delta E} \sim \frac{\hbar}{2mc^2}$$

$$\Delta x \sim c\Delta t \sim \frac{\hbar}{2mc}$$

Fig. 6. Vacuum polarization

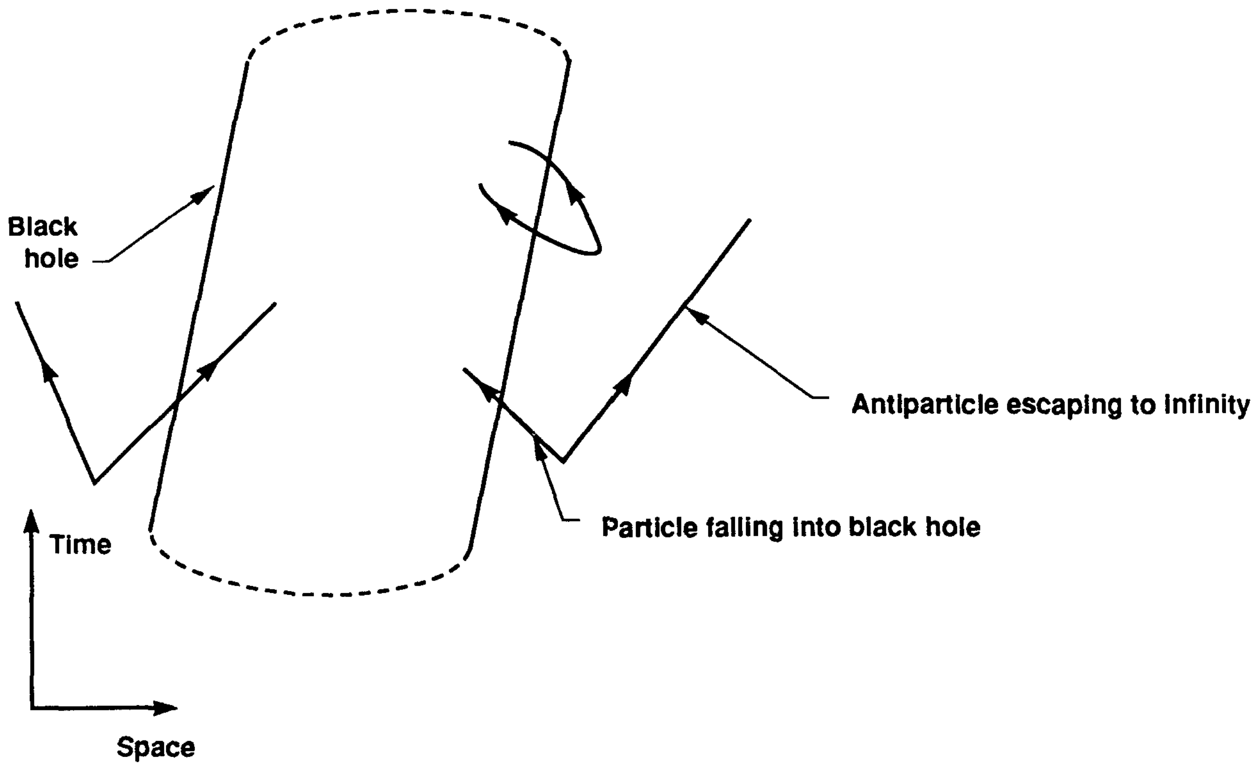


Fig. 7. Vacuum in presence of black hole: the hawking mechanism

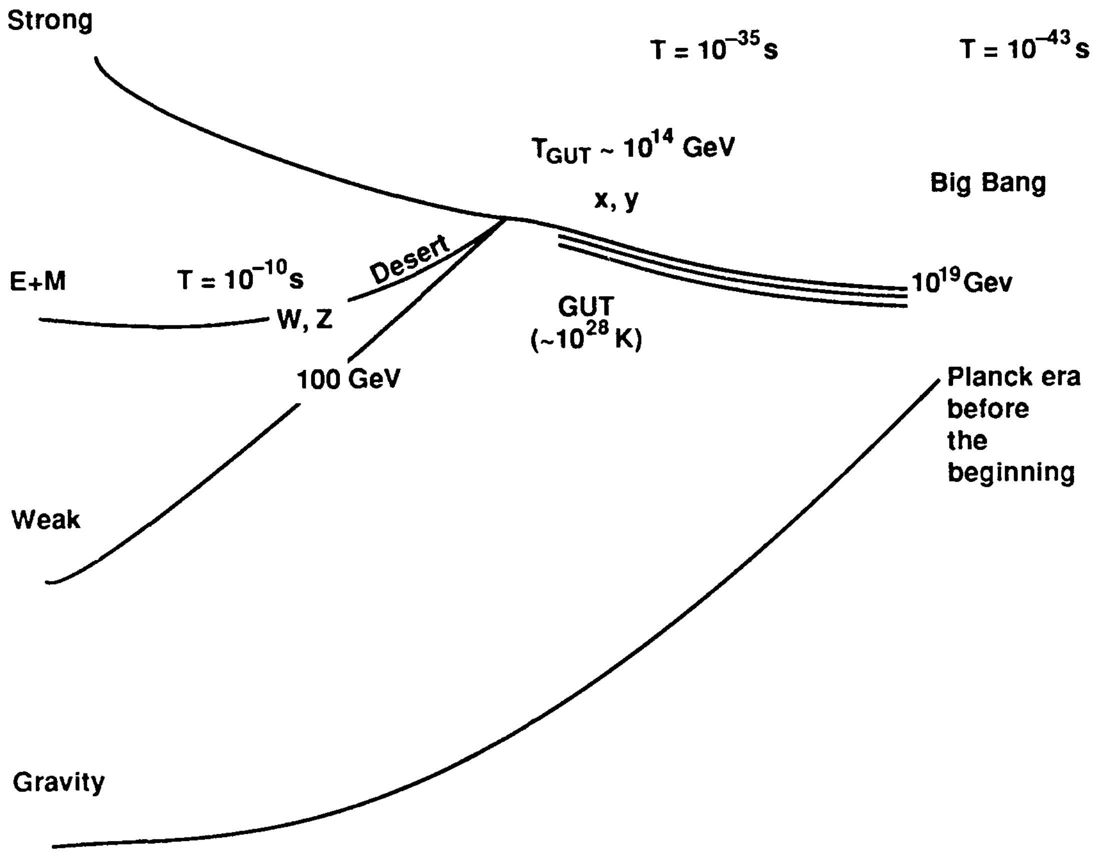
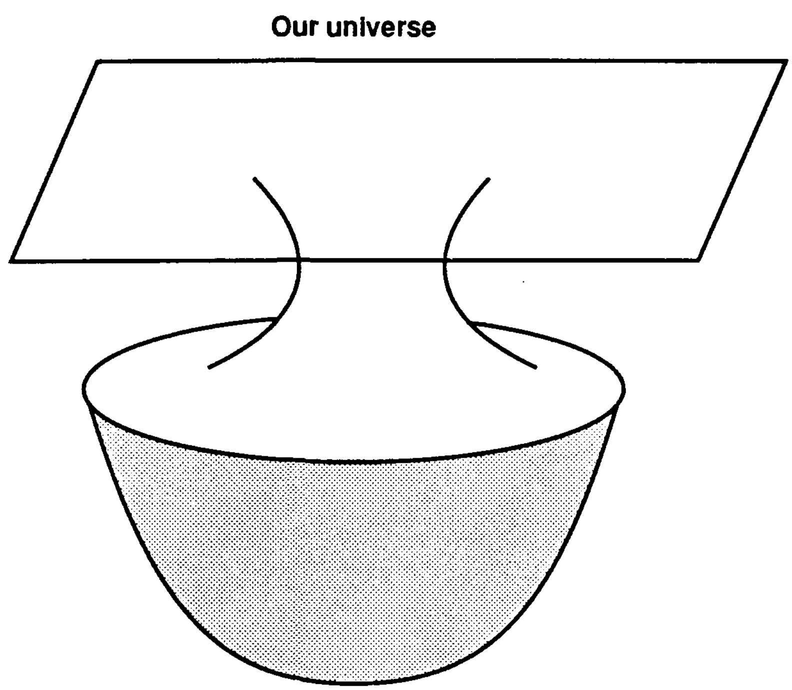


Fig. 8. Cosmic Landscape



(Adapted from A. Guth)

Fig. 9. Birth of a child universe

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Completely and Partially Polarized Signal Propagation in Single Mode Optical Fibers: Theory and Applications

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Abstract

A formalism for treating the effects of arbitrary, but relatively small linear perturbations on the polarization (and related properties) of the two component fundamental guided mode of a single mode optical fiber is presented. The approach is phenomenological in the sense that derived expressions relate to measurable quantities. Hence, the coherency equation of motion (CEM) is derived, integrated, and solved for the general case of arbitrary perturbations. The CEM is transformed to the stokes representation and the corresponding stokes form of the coherency evolution (SCE) or Mueller matrix is solved in closed functional form for several interesting special cases. The formalism was applied to the characterization of Polarization-maintaining fibers (PMF) and the design of PMF birefringent wavelength filters. The formalism has proven to be a powerful tool in calculation and design. In addition, the theory is in excellent agreement with measured data.

Introduction

Single mode (SM) fibers are the transmission medium of choice for long haul wideband telecommunications networks. Currently, SM fiber designs are receiving more attention from short haul systems such as coherent and conventional local area network applications. sensors, and integrated optical device technology. Important in many of these applications is the polarization behavior of signals propagating in SM fibers. The polarization phenomena of interest are signal changes associated with the state of polarization, the degree of polarization, polarization mode dispersion, polarization cross power coupling, and polarization selective loss (diattenuation[1]). These effects are generally due to intrinsic and/or extrinsic sources of birefringence and dichroism in SM fibers. In this paper, a phenomenalogical theory of the effects of birefringence and dichroism on the length and

wavelength dependence of the evolution of polarization phenomena of signals propagating in SM fibers is presented.

Formalism

The analysis of the polarization properties of SM fibers begins with the coupled mode equations[2] which results from the coupling of the two orthogonal transverse components of the fundamental (guided) mode by arbitrary perturbations. Assuming the monochromatic and time independent coupled fields are:

$$\vec{E}(r,\theta,z) = \sum_{l=1}^{2} a_l(z)\, \vec{E}_l(r,\theta) e^{i\beta_l z} \quad , \tag{1}$$

the coupled mode equations are expressed as

$$\frac{d\vec{a}(z)}{dz} = i\hat{K}(z)\cdot\vec{a}(z) \quad . \tag{2}$$

Here $\vec{a}$ is the vector representing the two orthogonal components of the perturbed field amplitudes which vary with propagation length, z. $\hat{K}(z)$ is the (2 x 2) matrix containing the coupling effects of the perturbations.

We seek a phenomenological theory and therefore are interested only in constructs directly associated with measurable quantities. The field amplitudes, however, are not directly measurable; but the elements of coherency matrix are directly measurable.[3] The coherency matrix is defined as $\hat{I}(z) = \vec{a}(z)\vec{a}(z)^*$, where * signifies complex conjugate. The coherency equation of motion (CEM); using the definition, Eq. (2), and its complex conjugate, is

$$\frac{d\hat{I}(z)}{dz} = i\{\hat{K}(z)\bullet - \bullet\hat{K}(z)^*\}\hat{I}(z) \quad . \tag{3}$$

$\{\hat{K}(z)\otimes - \otimes\hat{K}(z)^*\}$ is a coherency coupling operator which acts on $\hat{I}(z)$ at the position designated by $\otimes$. With this in mind Eq. (3) can be integrated using the Z-ordered exponential method[4] (see Appendix I) for a general coupling matrix, $\hat{K}(z)$. The result of this integration is the solution of the CEM,

$$\hat{I}(z) = \{\underset{\leftarrow}{Z} \exp [i\int_{z_o}^{z} (\hat{K}(z')\otimes - \otimes \hat{K}^*(z'))dz']\}\hat{I}(z_o). \tag{4}$$

The above equation is general. It can be integrated numerically for an arbitrary coupling matrix $\hat{K}(z)$. However, several simpler cases yield closed functional forms- In addition, these special cases offer powerful tools to characterize and design single mode fibers, polarization-maintaining fibers and fiber devices as well.

It is convenient to transform the matrix equation, Eq. (4), to a vector equation. This is accomplished by transforming to the stokes picture. Formally, this is permissible because of the underlying SU(2) symmetry of the transverse components electromagnetic field. The pauli spin basis matrices associated with SU(2) form a complete set in which any (2 x 2) matrix can be expanded.[5] The coefficients of the expansion are, in scattering and polarization optics, called the stokes parameters. The four stokes parameters (s_0, s_1, s_2, s_3) completely describe the state (polarization and magnitude) of an arbitrary of the electromagnetic field or signal. Before transforming to the stokes picture, an addition simplification is obtained by restricting the coupling matrix, $\hat{K}(z)$, to perturbations which induce only birefringence (retardance of the propaging signal) and dichroism (diattenuation of the propagation signal), as opposed to angular scattering and other effects. This is accomplished by casting $\hat{K}(z)$ in the form

$$\hat{K}(z) = \hat{B}(z) + i\hat{D}(z). \tag{5}$$

Assume both $\hat{B}(z)$ and $\hat{D}(z)$ are hermitian and represent the birefringence and dichroism effects, respectively.

Using this restriction in Eq. (4), the solution of the CEM for fields propagating in a fiber with arbitrary birefringence and dichroism along the propagation distance, z, is

$$\hat{I}(z) = \{\underset{\leftarrow}{Z} \exp [(i\int_{z_o}^{z} [\hat{B}(z'), \otimes]_- - \int_{z_o}^{z} [\hat{D}(z'), \otimes]_+)dz']\}\cdot\hat{I}(z_o). \tag{6}$$

$[\hat{B},\otimes]_- \equiv \hat{B}\otimes - \otimes\hat{B}$ in a commutation operator and $[\hat{D},\otimes]_+ \equiv \hat{D}\otimes + \otimes\hat{D}$ is an anticommutation operator. We transformed to the stokes picture by substituting

$$\hat{I}(z) = \tfrac{1}{2}(s_o(z)\hat{\sigma}_o + \vec{s}(z)\cdot\hat{\sigma}) \quad ,$$

$$\hat{B}(z) = \tfrac{1}{2}(\beta_o(z)\hat{\sigma}_o + \vec{\beta}(z)\cdot\hat{\sigma}) \quad ,$$

and

$$\hat{D}(z) = \tfrac{1}{2}(d_o(z)\hat{\sigma}_o + \vec{d}(z)\cdot\hat{\sigma}) \tag{7}$$

into Eq. (6).

Here $s_0(z)$ is the stokes parameter representing the total intensity of the field at position z. $\vec{s}(z) \equiv \{s_1(z),s_2(z),s_3(z)\}$ is the stokes vector and $s_1(z)$, $s_2(z)$, and $s_3(z)$ represents a measure of the linear on axis, the linear at 45° to the axis, and the circular states of polarization of the field at position z, respectively. β_0 is the initial (unperturbed) birefringent which is zero for our model. $\vec{\beta}(z) \equiv \{\beta_1(z),\beta_2(z),\beta_3(z)\}$and $\beta_1(z)$, $\beta_2(z)$, and $\beta_3(z)$ represents the birefringence in the linear on axis, the linear at 45° to the axis, and the circular stokes orientations at position z, respectively.[6] In addition, d_0 is the isotropic attenuation of the field at position z. $\vec{d}(z) \equiv \{d_1(z),d_1(z),d_2(z)\}$and $d_1(z)$, $d_2(z)$, and $d_3(z)$ represents the dichroism in the linear axis, the linear at 45° to the axis, and the circular stokes orientation at position z, respectively.[6] Finally, $\hat{\sigma}_0 = \begin{pmatrix}1&0\\0&1\end{pmatrix}$ and $\hat{\sigma}$ represents the pauli spin matrices $\{\hat{\sigma}_1,\hat{\sigma}_2,\hat{\sigma}_3\}$ where $\hat{\sigma}_1 = \begin{pmatrix}1&0\\0&-1\end{pmatrix}$, $\hat{\sigma}_2 = \begin{pmatrix}0&1\\1&0\end{pmatrix}$ and $\hat{\sigma}_3 = \begin{pmatrix}0&i\\-i&0\end{pmatrix}$, respectively. After substituting Eq. (7) into Eq. (6) and using both the (2 x 2) pauli spin

matrix algebra[7] and the (4 x 4) infinitesimal generators of the Lorentz z group (IGLG) algebra;[8] the stokes representation of the CEM for birefringence (retardation) and dichroism (diattenuation) is expressed as

$$\vec{\vec{s}}(z) = \{\underset{\leftarrow}{Z} \exp [\int_{z_o}^{z}((\vec{\beta}(z') \cdot \hat{\hat{B}}) - (d_o(z') \cdot \hat{\hat{I}}) - (\vec{d}(z') \cdot \hat{\hat{D}}))dz']\} \cdot s(z_o) \tag{8}$$

or

$$\vec{\vec{s}}(z) = \hat{\hat{M}}_G^{4x4}(z;z_o) \cdot \vec{\vec{s}}(z_o) \ . \tag{9}$$

Here, $\vec{\vec{s}}(z) \equiv \{s_0(z), \vec{s}(z)\}$ is the stokes 4-vector and $\hat{\hat{I}}$ is the (4 x 4) unit matrix, the $\hat{\hat{B}}$ matrices are the (4 x 4) IGLG which represent retardation (or rotation of the field), and the $\hat{\hat{D}}$ matrices are the (4 4x4) IGLG which represents diattenuation (or polarization selective attenuation of the field). The explicit form of $\hat{\hat{B}}$ and $\hat{\hat{D}}$ are given in Appendix II. Eq. (8) is *the stokes form* of the CEM. It is also known as the Stokes-Mueller matrix equation. The exact form of the general stokes coherence evolution (SCE) matrix or Mueller matrix for birefringence and dichroism is, then,

$$\hat{\hat{M}}_G^{4x4}(z;z_o) = \{\underset{\leftarrow}{Z} \exp [\int_{z_o}^{z}((\vec{\beta}(z') \cdot \hat{\hat{B}}) - (d_o(z') \cdot \hat{\hat{I}}) - (\vec{d}(z') \cdot \hat{\hat{D}}))dz']\} \tag{10}$$

While the SCE matrix is exact. it is not, in general, expressible in closed functional form. Thus it must be evaluated by expanding the Z-order exponential and utilizing numerical methods. However, the SCE is expressible in close functional form for several interesting special cases which are applicable to the characterization and design of single mode fiber, polarization-maintaining fiber, fiber optic devices as well as characterizing the more general forward scattering problem for the propagation of electromagnetic fields and signals in arbitrary dielectric media

Special Cases

Case (1) Birefringence only (i.e., ($|\vec{\beta}(z)| >> |\vec{d}(z)|$): Completely Polarizing Case.

If the SM fiber has birefringence only, the (SCE) matrix, after expanding the exponential in Eq. (10) and utilizing the (4 x 4) IGLG algebra is expressible in the following closed functional form

$$\hat{M}_\beta^{4x4}(z;z_o) = \underset{\leftarrow}{Z} \exp\left[\int_{z_o}^{z} \beta(z')dz'\,(\vec{e}_\beta\cdot\hat{\hat{B}})\right]$$

or

$$\hat{M}_\beta^{4x4}(z;z') = \hat{\hat{I}} + \sin\left[\int_{z_o}^{z}\beta(z')dz'\right](\vec{e}_\beta\cdot\hat{\hat{B}}) + \left(1-\cos\left[\int_{z_o}^{z}\beta(z')dz'\right]\right)(\vec{e}_\beta\cdot\hat{\hat{B}})^2\ , \tag{11}$$

Here $\beta(z')$ is the magnitude of the birefringence and $\vec{e}_\beta$ is its z independent unit vector. A simple and interesting (translational invariant) case, is the case of constant birefringence with z. The SCE matrix is

$$\hat{M}_\beta^{4x4}(z-z_o) = \hat{\hat{I}} + \sin[\beta(z-z_o)]\,(\vec{e}_\beta\cdot\hat{\hat{B}}) + (1-\cos[\beta(z-z_o)])(\vec{e}_\beta\cdot\hat{\hat{B}})^2. \tag{12}$$

A more convenient form of Eq. (12) is found by recognizing its block diagonal form; that is,

$$\hat{\hat{M}}_{\beta\,(z)}^{4\times4} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & & & \\ 0 & & \hat{M}_{\beta\,(z)}^{3\times3} & \\ 0 & & & \end{bmatrix}. \tag{13}$$

with

$$\hat{\mathcal{M}}_{\beta}^{3x3}(z) = \vec{e}_\beta \vec{e}_\beta + [1-\vec{e}_\beta \vec{e}_\beta] \cos(\beta z) + (\vec{e}_\beta \times \cdot) \sin(\beta z) \tag{14}$$

and $z_0 = 0$. Eq. (14) represents non-depolarizing, but arbitrary, constant birefringence. The birefringence rotates the SOP of the incident field in a generalized manner in stokes space.[9] The degree of polarization, P, is defined as

$$P \equiv \left[\frac{\vec{s}(z) \cdot \vec{s}(z)}{s_0^2(z)} \right]^{1/2} . \tag{15}$$

Substituting Eq. (11) into Eq. (15) results in the expected conclusion: that is, P = 1, independent of z. Therefore, Eq. (11) through Eq. (14) apply to non-depolarizing birefringence.

Case (2) Stochastic Birefringence and Source Fluctuations: Partially Polarized Case.

(i) Polarization Cross Power Coupling.

A measure of the polarization-holding[10] ability (over long propagation distance) of a linear birefringence SM fibers is the extinction ratio. Assuming a monochromatic field, the extinction ratio is defined as the ratio (usually expressed as $\log_{10}$) of the power coupled from the initially excited eigen-polarization, say, Ixx, to the initially unexcited orthogonal eigen-polarization, Iyy, over a propagation distance, z.

The theory of random coupling[11] due to discrete perturbations on SM fiber gives the following functional form for the extinction ratio

$$\eta = \log_{10}\left[\frac{Iyy(z)}{Ixx(z) + Iyy(z)}\right] = \log_{10}[\tfrac{1}{2}(1-e^{-2hz})] \tag{16}$$

where h is the cross coupling parameter.

Transforming to the stokes picture, the SCE matrix for polarization cross power coupling, due to random coupling, is

$$<\hat{M}^{3x3}(z)>cc = \{e^{-2hz}\hat{I}_{3x3}\} \;, \tag{17}$$

where $\hat{I}_{3x3}$ is the (3x3) unit matrix.

In addition, one can show that the degree of linear (on eigen-axis) polarization is

$$P_L \equiv \left|\frac{\vec{s}_1(z)}{s_0(z)}\right| = e^{-2hz} \leq 1 \;. \tag{18}$$

The results illustrates a mechanism for depolarization of a monochromatic eigen-polarization component (i.e., s_1 component) over a propagate length, z.

(ii) Source Fluctuations

Real sources have finite spectral width which in the presence of birefringence lead to polarization-mode[12] (PMD). PMD is a measure of the delay in time per unit length between the fast and slow propagating orthogonal components of an incident polarized signal. Ultimately PMD characterizes the propagation distance at which incoherence occurs for an initially polarized signal with spectral width, $\Delta\lambda$, and SM fibers with birefringence, β. When the delay time, τ_d of a signal propagating a certain distance, z, increases beyond the coherence time, τ_c, of the source; the signal becomes incoherent and ceases to transmit

useful information. This mechanism for depolarization of off axis polarization component (i.e., either s_2 or s_3 or both) is due to source fluctuations. A recent study[13] gave an expression for this type of depolarization. In our notation, it is expressed as

$$<\hat{M}(z)>_s^{3x3} = \{\vec{e}_\beta\vec{e}_\beta + [1-\vec{e}_\beta\vec{e}_\beta]e^{-d_s z}\} \tag{19}$$

where $d_s = d_s(\Delta\lambda)$ is the phenomenological depolarization parameter.

(iii) Fluctuating Birefringence

An additional mechanism for depolarization is fluctuating intrinsic birefringence about some mean birefringence. Assume monochromatic incident field in the presence of random, guassian fluctuations of the birefringence along the propagation length, z, of a SM fiber. After applying methods related to multiplicative stochastic processes[14], the following SCE matrix is derived.

$$<\hat{M}^{3x3}(z)_\beta> = \{\vec{e}_\beta\vec{e}_\beta + [1-\vec{e}_\beta\vec{e}_\beta]\}e^{-d_\beta z} \quad , \tag{20}$$

Here d_β is a phenomenological parameter characterizes the fluctuations of the birefringence. This type of depolarization again effects the off axis polarization components and is due to fluctuating intrinsic birefringence.

(iv) Completely and Partially Polarized Case.

The general (3 x 3) SCE matrix for completely and partially polarized signals in birefringent SM fibers is (since $\hat{M}_\beta^{3x3}(z)$, $<\hat{M}(z)>_{cc}^{3x3}$, $<\hat{M}(z)>_s^{3x3}$ and $\hat{M}(z)_\beta^{3x3}$ commute),

$$<\hat{M}(z)>_G^{3x3} \equiv \hat{M}_\beta^{3x3}(z)<\hat{M}(z)>_{cc}^{3x3}<\hat{M}(z)>_s^{3x3}<\hat{M}(z)>_\beta^{3x3} \quad , \tag{21}$$

or

$$<\hat{M}(z)>_G^{3x3} = \vec{e}_\beta\vec{e}_\beta e^{-2hz} + \{[1-\vec{e}_\beta\vec{e}_\beta]\cos(\beta z) + (\vec{e}_\beta\times\cdot)\sin(\beta z)\}e^{-f(d_s,d_\beta,h)z} \tag{22}$$

where $f(d_s,d_\beta,h)$ is the phenomenological depolarization parameter related to both the source and the medium fluctuations. The stokes parameters are measurable. So all the parameters in the above SCE matrix measurable functions of various quantities (i.e., length, wavelength, etc.).

Case (3) Dichroism Only (i.e., ($|\vec{d}(z)| >> |\vec{\beta}(z)|$):

The SCE matrix for a SM Fiber with perturbation which produces essentially dichroism (diattenuation) is, using Eq. (10),

$$\hat{M}_D^{4x4}(z;z_o) = \exp[-\int_{z_o}^{z} d_o(z')dz']\{\underset{\leftarrow}{Z}\exp[-\int_{z_o}^{z} d(z')dz'(\vec{e}_d\cdot\hat{\vec{D}})]\}. \tag{23}$$

Assuming the dichroism is constant along z (i.e., translational invariance), expanding the exponential, and using the (4 x 4) IGLG algebra, the above simplifies to the following closed functional form.

$$\hat{M}_D^{4x4}(z-z_o) = e^{-d_o z}\{\hat{\vec{I}} + \sinh[d(z-z_o)]\,(\vec{e}_d\cdot\hat{\vec{D}}) + (\cosh[d(z-z_o)]-1)\,(\vec{e}_d\cdot\hat{\vec{D}})^2\} \;\cdot \tag{24}$$

This matrix is analogous to the boost of the Lorentz transformations of special relativity.[8] It indicates the effects of the polarization dependent loss of a SMF. The total loss is composed of the isotropic dichroism, do, and the magnitude of the oriented dichroism, $d = \sqrt{d_1^2 + d_2^2 + d_3^2}$.

A linear SM fiber polarizer is a linear dichroic medium. The SCE matrix for translational invariant linear on axis dichroism is

$$\hat{M}_D^{4x4}(z) = \hat{I} + \sinh(d_1 z)(\vec{e}_1 \cdot \hat{\hat{D}}_1) + [\cosh(d_1 z) - 1](\vec{e}_1 \cdot \hat{\hat{D}}_1)^2 \quad . \tag{25}$$

Using this CE matrix in the Stokes-Mueller equation, Eq. (8), the degree of polarization, P, for an unpolarized incident field is

$$P = \tanh(d_1 z) \leq 1 \quad . \tag{26}$$

Hence, the degree of polarization increases towards 1 (i.e., perfect polarizer) as z increases at a rate determined by the tangent of the linear dichroism, d_1 .

Applications and Conclusion

The formalism developed above unifies the theoretical treatment of several important polarization related phenomena. The phenomenological approach insures results which are expressible as measurable quantities. Central to the approach is the theoretical determination of effects of perturbations on the SCE matrix, or Mueller matrix, for the general case as well as several special cases. The formalism has been applied to the characterization of the polarization properties of AT&T's rectangular polarization maintaining (PM) fiber.[15] Also, the formalism has also been utilized in the analysis of an elasto-optic point perturbation beat length measurement technique.[16] Figure 1 shows the comparison of measured beat length data with theory (see reference 16). The agreement is excellent. More recently, the formalism was used to tackle the difficult problem[17] of designing PM fiber birefringent wavelength filters. Using the formalism, calculations of various filter designs were simple and straight forward. In addition, a computer simulation of birefringent wavelength filters was developed based on the above formalism and used to model such optical components as waveplates, polarizers, absorbers, etc.[18] The theory and the computer simulations prove to be an essential tool in the design, the characterization, and the evaluation of prototype PM Fiber birefringent wavelength filters.[19] Figure 2 shows the comparison of the theory to the prototype data. Again, the agreement is excellent (see Ref. 19).

Appendix I: Z-ordered Exponential Operator[4]

Consider $\hat{M} = \underset{\leftarrow}{Z} \exp\left[\int_{z_0}^{z} \hat{m}(z')dz' \right]$. The $\underset{\leftarrow}{Z}$ signifies z ordering such that all greater z distances are ordered to the left. That is,

$$\underset{\leftarrow}{Z} \exp \{ \int_{z_o}^{z} \hat{m}(z')dz' \} = \hat{1} + \sum_n \int_{z_o}^{z} dz'_1 \int_{z_o}^{z} dz'_2 \cdots \int_{z_o}^{z_{n-1}} dz'_n (\hat{m}(z'_1)\hat{m}(z'_2) \cdots \hat{m}(z'_n)) \quad .$$

This operation properly accounts for the possible non-communitivity of the operators at different distances along z.

Appendix II

The infinitesimal generators of the Lorentz group[8] are given by:

$$\hat{\hat{B}}_1 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}, \quad \hat{\hat{B}}_2 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}, \quad \hat{\hat{B}}_3 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix},$$

and

$$\hat{\hat{D}}_1 = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}, \quad \hat{\hat{D}}_2 = \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}, \quad \hat{\hat{D}}_3 = \begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix},$$

and

$$\hat{\hat{I}} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}.$$

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Non-Modulating Elasto-Optic Point Perturbation Data Compared to Theoretical Model

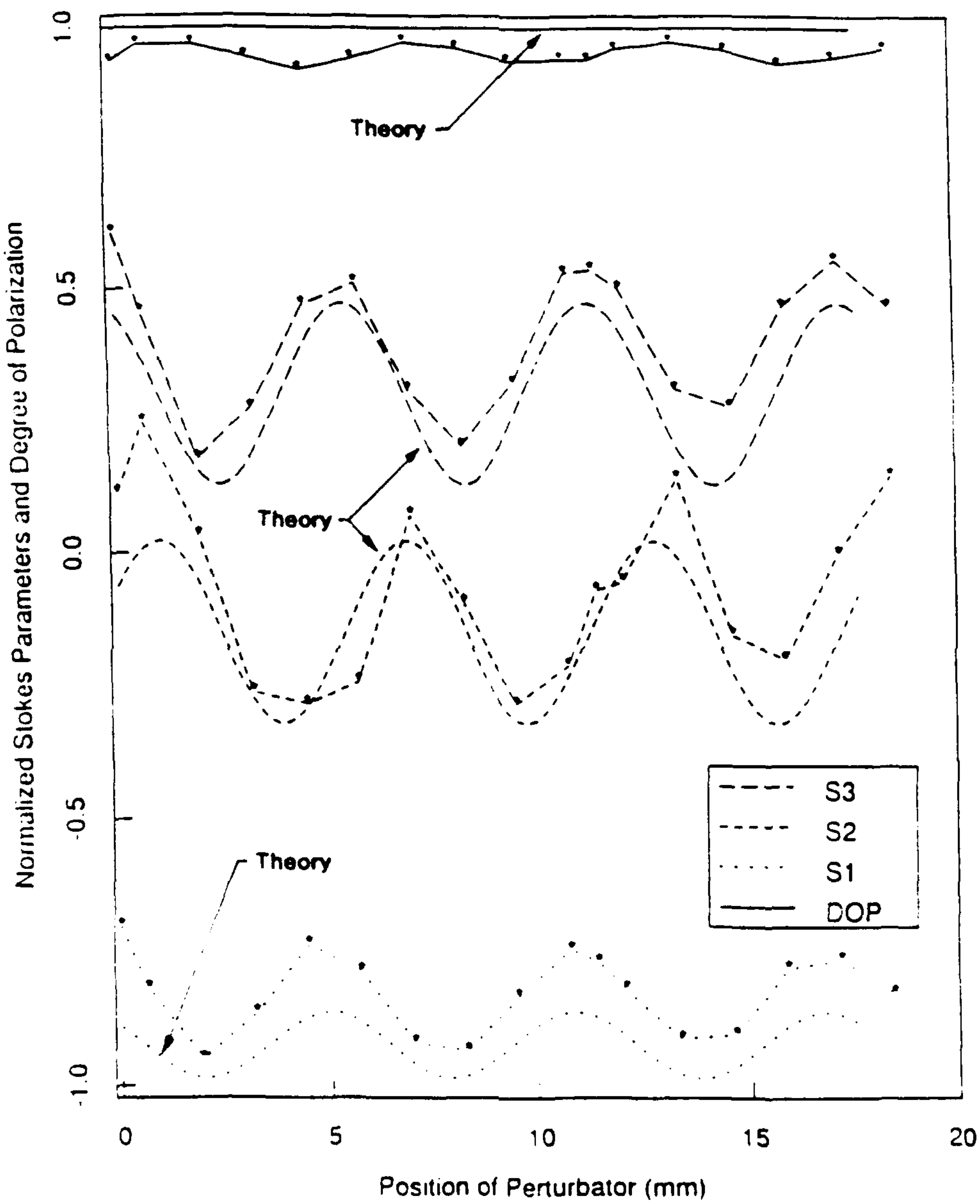

Fig. 1. Comparison of the non-modulating elasto-optic point perturbation data and the theoretical model.

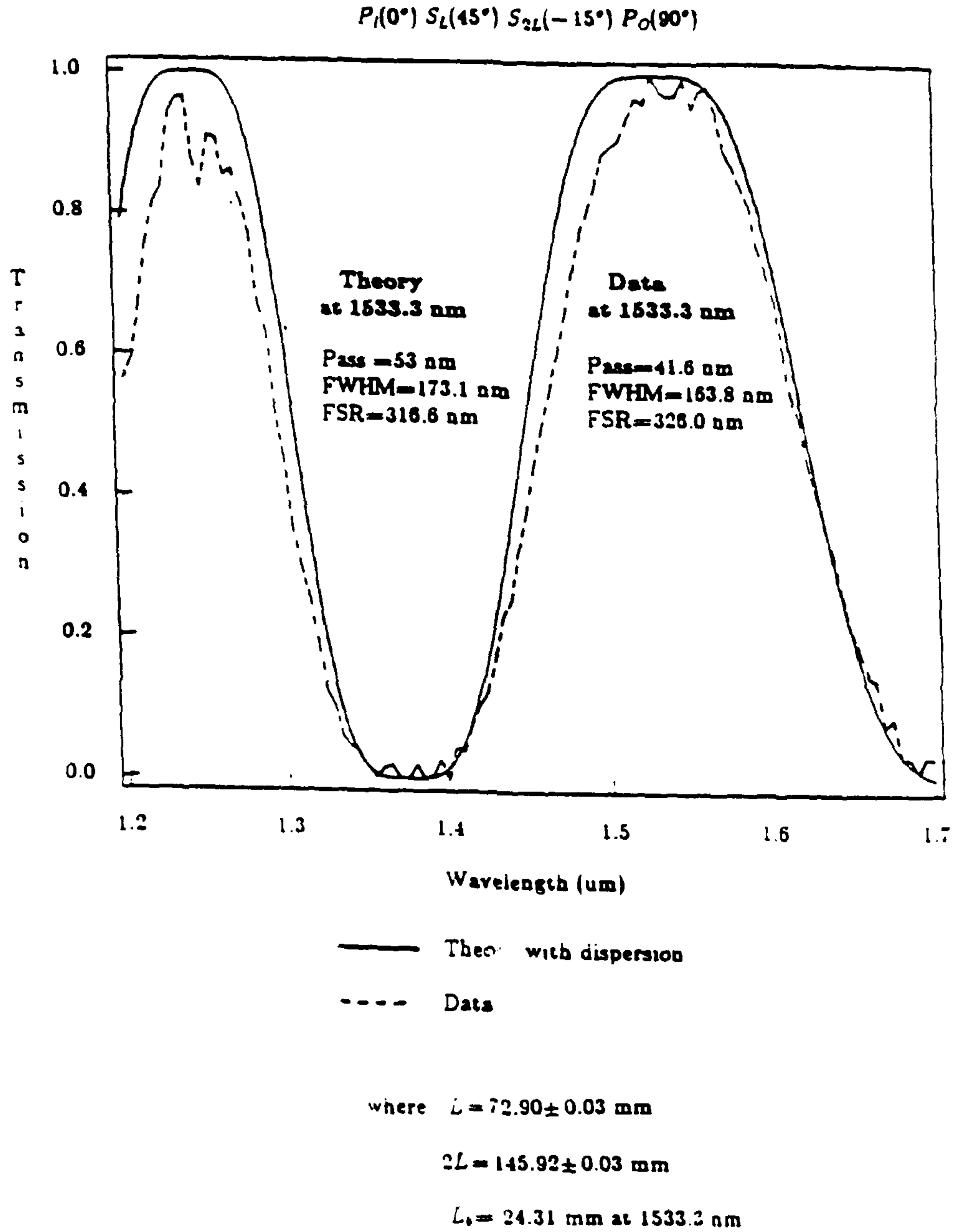

Fig. 2. A comparison of the theory (including dispersive effects) and data for the normalized spectral response of the prototype filter, $P_I(0°)S_L^{Lb}(45°)S_{2L}^{Lb}(-15°)P_o(0°)$.

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Is the Jet in Quasar 1038+064 Precessing?

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Abstract

Radio images of the flat spectrum, high redshift (z=1.127) quasar 1038+064 at different wavelengths are presented. It has a jet which appears to be performing angular motion. We show that the jet possesses an apparent angular velocity of: $3 \times 10^{-13}\ h\beta_{app}s^{-1}$($H_O$=100 hkms^{-1} Mpc^{-1}). We estimate $\beta_{app} \approx 3$.

Introduction

The causal naked-eye observer is aware of the fact that the universe appears to be populated by stars. In fact, in the course of a year the naked-eye observer will be able to see thousands of stars. Few people, however, realize that the number of stars in the universe is enormous. Perhaps the universe contains 10^{20} stars or so.

Does the universe consist of just individual stars not spatially related or does the universe have structure? That is we are asking are the stars, which populate the universe randomly distributed or do they come in groups? - The answer to our question is yes. The universe of stars is structured. The next question is: How is the universe structured? - The answer is the stars form large groups, which are called galaxies. How many stars does each galaxy contain? - 10^{10} stars. How many galaxies are there in the universe - 10^{10} galaxies. Is the sun located in a galaxy too? - Yes. What is the name of the galaxy that our sun and earth are located in? - Milky-Way. In fact, all of the stars we see with our naked-eyes are contained in the Milky-Way.

As far as we know each and every star in the universe is contained in a large conglomeration of stars, which are called galaxies. That is to our knowledge there are no single stars which are not contained in a galaxy. So we see that the basic building blocks of the universe are not stars, as the causal naked-eye observer would think rather galaxies, which are simply put aggregates of stars.

We now turn to a fundamental question about galaxies that was posed and answered by the American astronomer Edwin Hubble in 1929. The question is: Do galaxies possess ordered motion? Hubble was able to answer this question in the affirmative. The next question is: How do the galaxies move? - They are moving apart from each other. How was Hubble able to prove that the galaxies are moving apart from each other? - He used the Doppler effect. How was Hubble able to measure the doppler effect on distant galaxies? - He measured the shift of spectral lines to determine the velocity of a galaxy. Hubble showed that the father away a galaxy is the faster it is moving away from us.

Summing it up, we can say that Hubble showed that the universe is expanding. By this we mean that the galaxies are moving away from each other in an orderly fashion. We talk about the "Expansion of the Universe". Hubble depicted the expansion of the universe graphically in a velocity (or redshift) vs. distance diagram for galaxies. Such a diagram is now called the Hubble Diagram. We come to two conclusions: (l) The universe was smaller in the past (2) The universe will be larger in the future.

How large is the universe? - All we have to do is to carry the Hubble Diagram out to the speed of light. The result is: 10-20 billion light years or about 5,000Mpc. How old is the universe - 10-20 billion years or roughly 10^{10} years. We conclude: (l) The universe has a finite age (2) The universe has a finite size.

We know the present condition of the universe. Now we want to inquire into the past and future of the universe. Let's consider the past first. If we follow the expansion back into the past we see the universe began as a place of extremely high density, pressure and temperature. We call this the Big Bang. How do we know that the Big Bang really took place? - Because during the hot phase of the universe radiation must have dominated. Now the radiation due to the expansion of the universe would have cooled to a theoretically predicable temperature of 3K. Such a radiation field has been found. We conclude: (l) The chemical elements as we know them today could not have existed at the beginning of the

universe (2) Neither the galaxies nor the stars could have existed in the early part of the universe. Therefore, we are living in an evolving universe. Two of the basic unanswered questions are: (1) When in the evolution of the universe were the galaxies formed? (2) How did they form?

Now that we know the past and present universe. We ask: what is the fate of the universe? - We do not know. However we do know that there are three possibilities: (1) Expansion forever - Open Universe (2) Termination of Expansion - flat universe (3) Contraction - closed universe (Big Crunch).

With this background we are now in a position of understanding and appreciating quasars. What are quasars? - They are starlike objects with high redshifts. That is they look just like stars, but their redshifts are prodigious. Remember Hubble's work means there is a relationship between redshift and distance. The farther away a galaxy is the higher its redshift. From the redshift alone we would conclude that quasars are very far away. At what we call cosmological distances. Now if quasars really are very far away then their measured brightness indicates that they are producing much more energy than the brightest of galaxies. About 100 times more. In fact, the deepest quasar mystery is: What is responsible for the enormous energy output? - Although there is little observational evidence most astrophysicists think a black hole must be responsible. What is a black hole? It is a body whose gravitational field is so strong that it can not emit any electromagnetic radiation whatsoever. It is believed that quasars are powered by massive black holes through the accretion of matter on to them.

Quasars are believed to possess the following structure: (1) A core, which is presumably a massive ($M \geq 10^8 M_0$) black hole. It is surrounded by an accretion disk. Only a few gravitational radii from the central black hole the observed continuum radiation is created, (2) A broad line emission region (BLR) only about 1pc from the center, (3) An intermediate zone located between the BLR and the narrow emission line region (NLR) and (4) The NLR, which extends from tens to hundreds of parsecs from the center. This entire quasar structure is thought to be imbedded in the central region of a host galaxy, which for radio-loud quasars like 1038+064 is believed to be an elliptical galaxy. This structure was inferred from optical observations. However, a small percentage of quasars are radio-loud. The radio picture of a quasar may contain a jet. One fundamental question that we will address is: Where in the optically derived quasar structure is the jet emitting region located?

Most if not all astronomical objects rotate. Rotation, however, is often difficult to detect. Rotating regions of nebulosity, which are presumably part of the host galaxy, have been found relatively far (kiloparsecs) from the quasar centers (Bergeron et al., 1983; Hintzen and Stocke, 1986). Thus, only in low redshift quasars, where the host galaxies can be seen, has angular motion so far been observed. To date neither has a rotating quasar jet been found nor has it been demonstrated that the basic quasar structure as described above rotates. In the following we present observational evidence, which indicates that for the first time angular motion has been observed in a high redshift quasar, where the host galaxy remains beyond the limit of detectability. We find that we may be observing angular motion at parsec distances.

The quasar, 1038+064 (4C06.04), detected in our last meter wavelength survey (Akujor et al., 1989) is a flat spectrum radio source with α = -0.05, ($S \sim v^{-\alpha}$), (Wills and Bolton, 1969), with a measured redshift, z = 1.127 (Linds and Wills, 1972) and apparent magnitude, m = 16.7 (Véron and Véron, 1989). Burns et al., (1981) and Hintzen et al., (1983) had suggested a "head tail" structure for this source which is the direction of a "poor cluster, WP13" (Burns et. al., 1981). Further investigation of this object was therefore necessary. No QSO has been spectroscopically confirmed to belong to a cluster and no QSO with classical head-tail (e.g. NGC1265; Owen et al., 1978) or an FRI morphology has been found either. Our observations with the VLA and MERLIN show that 1038+064 is a 'corejet' source. However, the jet shows changes in position angle that suggest angular motion of the jet.

Observations and Results

The object was observed with the VLA in A-configuration at 90 cm and 6 cm on 8 September, 1987. The observations were snap shots of 5 minutes each, and the calibration was done at the VLA by P. Perley. MERLIN (Thomasson, 1986) observations were made at 6 cm and 18 cm on 4 January, 1988 and 14 May, 1988, respectively. At 6 cm the source was tracked for 14 hours, while at 18 cm it lasted for 18 hours.

VLA data was reduced with the local AIPS package, while MERLIN data reduction was made with the interactive Jodrell Bank OLAF routine, employing the self-calibration technique; (Cornwell and Wilkinson, 1978). The flux density calibration was made on the scale of Baarstal (1977). The restoring beams on the VLA maps (Figs. 1 and 2) are 1.5 x 1.5 arcsec and 0.35 x 0.35 arcsec at 90 cm and 6 cm respectively; while corresponding

noise levels in the maps are 2 mJy and 0.5 mJy. The MERLIN maps (Figs. 3 and 4) have restoring beams of 0.25 x 0.25 arcsec and 80 x 80 mas at 18 cm and 6 cm respectively; the corresponding rms noise of the source are 3 mJy and 1.0 mJy.

The figures (1-4) are arranged in order of increasing resolution. At low frequency (Fig. 1) we detect extended emission stretching about 7 arcsec (FWHM) across. The maps at high resolution (Figs. 2-4), taken together show that 1038+064 has a strong core containing about 90 percent of the total flux and a jet position angle whose position angle changes from 230° to 250°. Also, the path of the jet at initial P.A. is longer, consistent with clockwise angular motion of the core, in which material emitted earlier would have covered some distance before subsequent emission. The path of the jet is sketched in Fig. 5.

Discussion

We will answer the following questions: (i) What is the angular velocity and (ii) In which part of the quasar is the jet emitting region located. We will assume that a) the apparent bulk velocity, $v_{app} = c\beta_{app}$ of the jet is constant and b) the apparent angular velocity of the jet is a constant.

First we calculate the apparent angular velocity, ω_{app} Consider the relationship between jet length, l_i vs. position angle, θ_i. From the radio maps we find: l_1 = 1".77, l_2 = 0".48, l_3 = 0".16; θ_1 = 248.1°, θ_2 = 232.7°, θ_3 = 226.1°. The observed linear relationship (see Fig. 6) is:

$$l_i = a\theta_i + b \tag{1}$$

It possesses a correlation of .994 and a standard deviation of .13". We have:

$$a = \frac{dl}{d\theta} = \frac{dl}{dt}\,\frac{dt}{d\theta} = \frac{1}{\omega_{app}}\,\frac{dl}{dt} \tag{2}$$

From Fig. 5 we see that the following equations are valid.

$$L_i = \mu t_i \quad or \quad \mu = \frac{dl}{dt} \tag{3}$$

where t_1, t_2, and t_3 refer to the travel time of the jet material in the different directions observed and μ is the proper motion of the emitted material. Inserting (3) into (2) leads to:

$$a = \frac{\mu}{\omega_{app}}$$

From Fig. 6 we obtain: a = 4.3" ± .5. In order to calculate ω_{app} from (4) we need to know μ. However, μ is not measured. It must be calculated from the bulk velocity of the jet. We obtain $\mu = .035h\beta_{app}$mas yr^{-1} with $H_0 = 100h$ ms^{-1}Mpc^{-1} and $q_0 = 0.5$ for 1038+064. We find an apparent angular velocity of:

$$\omega_{app} = 3\times10^{-13}\, h\beta_{app}s^{-1}$$

We estimate β_{app} using the unified beaming model of Orr and Browne (1982) which relates via the following equations the ratio of core to extended flux density, R, of core-dominated sources to ϕ, the viewing angle, the jet velocity, β, and to the factor R_T=R(90°).

$$R = \frac{R_T}{2}\left[\frac{1}{(1-\beta\cos\phi)^2} + \frac{1}{(1+\beta\cos\phi)^2}\right]$$

$$R_T = 0.024\frac{\nu}{5000}(1+z)$$

For 1038+064, we have R = 0.9, R_T=.051 and following Orr and Brown a Lorentz factor $\gamma \approx 5$. We obtain a viewing angle $\phi \approx 33°$. From Pearson and Zensus (1987) we have:

$$\beta_{app} = \frac{\beta\ \sin\phi}{1-\beta\cos\phi}$$

which yields the apparent jet velocity, $\beta_{app} \approx 3$. This means our value for the apparent angular velocity is: $\omega_{app} = 9 \text{ X } 10^{-13}$hs^{-1} or $\omega_{app} \approx 10^{-12}$hs^{-1}.

Our calculation of the angular velocity is independent of the nature of the angular motion. We now ask the basic question: Does the observed angular motion of the jet correspond to precessional or rotational motion of the jet emitting region? It is believed that jets are emitted along the axis of rotation of the central engine. If this is so, then jets can not rotate, consequently, the observed angular motion would be due to precession. If the jet emitting region is precessing then there are two possibilities: (1) Coincidentally, the plane of the precessional motion is in the plane of the sky. Then ω_{app} would be the true precessional angular velocity and ϕ the angle between the rotation axis and the line of sight. We see that ω_{app} can be due to either precession or rotation. (2) If the plane of the precessional motion is not coincident with the plane of the sky, then ϕ changes and consequently, β_{app} and ω_{app} are not constant either. In fact, if the jet emitting region is rotating and not precessing then we also have ω_{app} is not a constant unless the plane of the rotational motion happens to lie in the plane of the sky. This is because in general true circular motion appears as apparent elliptical motion, when the line of sight is not parallel to the angular momentum vector. It is clear our data is not sufficient to compute any variation in ω_{app} We conclude that from our data it is not possible to differentiate between precessional and rotational motion.

Finally, we attempt to obtain a rough estimate of the distance, r, of the jet emitting region from the center of the quasar. In order to accomplish this we will make two assumptions: (1) The jet emitting region is revolving around the central engine to which it is gravitationally bound (2) The plane of this motion is coincident with the plane of the sky. Our first assumption means the validity of the following well known formula:

$$M = \frac{rv^2}{G} \tag{4}$$

where G is the constant of gravitation. Combining this with $v=\omega r$ we have:

$$r = \left(\frac{GM}{\omega^2}\right)^{\frac{1}{3}} \tag{5}$$

Equation (5) contains ω, the true angular velocity, and not ω_{app}, which is the apparent angular velocity measured in the plane of the sky. In order to compute ω we need to know the angle, i, of the true orbit with the line of sight. This angle is unknown. In order to obtain a rough estimate of r we let $\omega = \omega_{app}$ That is we assume that the plane of the circular motion is coincident with the plane of the apparent orbit. The validity of this assumption

may not be improbable. The angular motion we have found has not been seen before and the question is why. It may be because coincidentally the angular momentum vector of the jet emitting region in 1038+064 is parallel to the line of sight. Now inserting $M \geq 10^8 M_o$ (Blandford, 1979, 1985) we see that the jet emitting region must lie at $r \geq 17(h\beta_{app})^{-2/3}$pc. With our estimate of $\beta_{app} \approx 3$ we find that $r \geq 8$pc.

Conclusions and Summary

Firstly, we presented evidence which demonstrates that the jet of the quasar 1038+064 possesses angular motion. Secondly, we calculated an apparent angular velocity of $3 \times 10^{-13} h\beta_{app} s^{-1}$ Thirdly, we pointed out that our data does not allow us to differentiate between precessional and rotational motion of the jet emitting region.

Jets are believed to be emitted close to the quasar black hole. Just how close is not known. Under the assumptions of rotational motion of the jet emitting region and an inclination angle of 0°, we demonstrated that in 1038+064 the jet emitting region may be situated at $r \geq 17(h\beta_{app})^{-2/3}$pc from the quasar center. With our estimate of $\beta_{app} \approx 3$ we find that $r \geq 8$pc. Due to the assumptions involved we can not emphasize the precise numerical value for the distance of the jet emitting region from the quasar center, however our result does seem to indicate that angular motion of a quasar jet may have been observed at parsec distances from the central engine.

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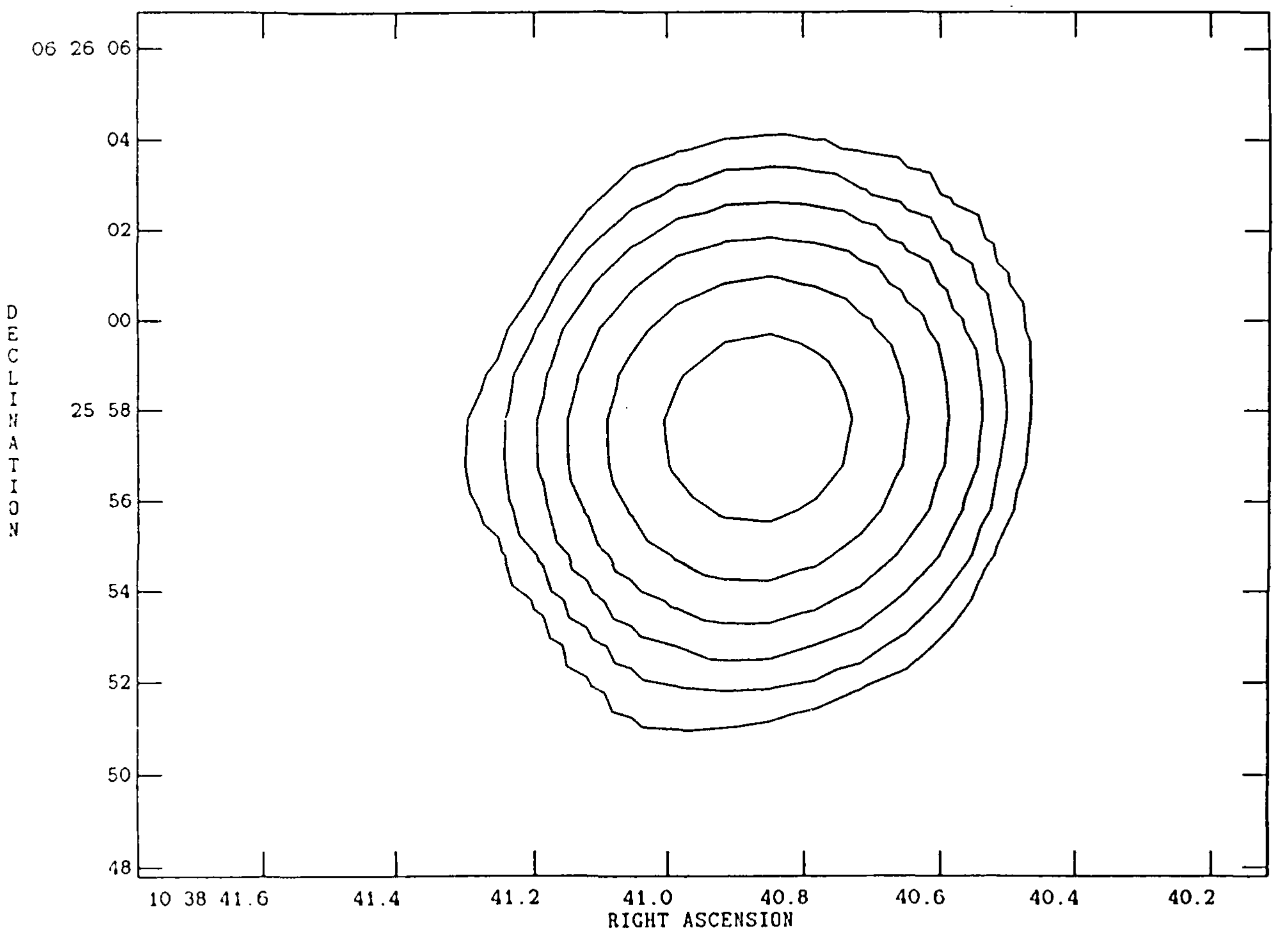
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RIGHT ASCENSION

Figure 1

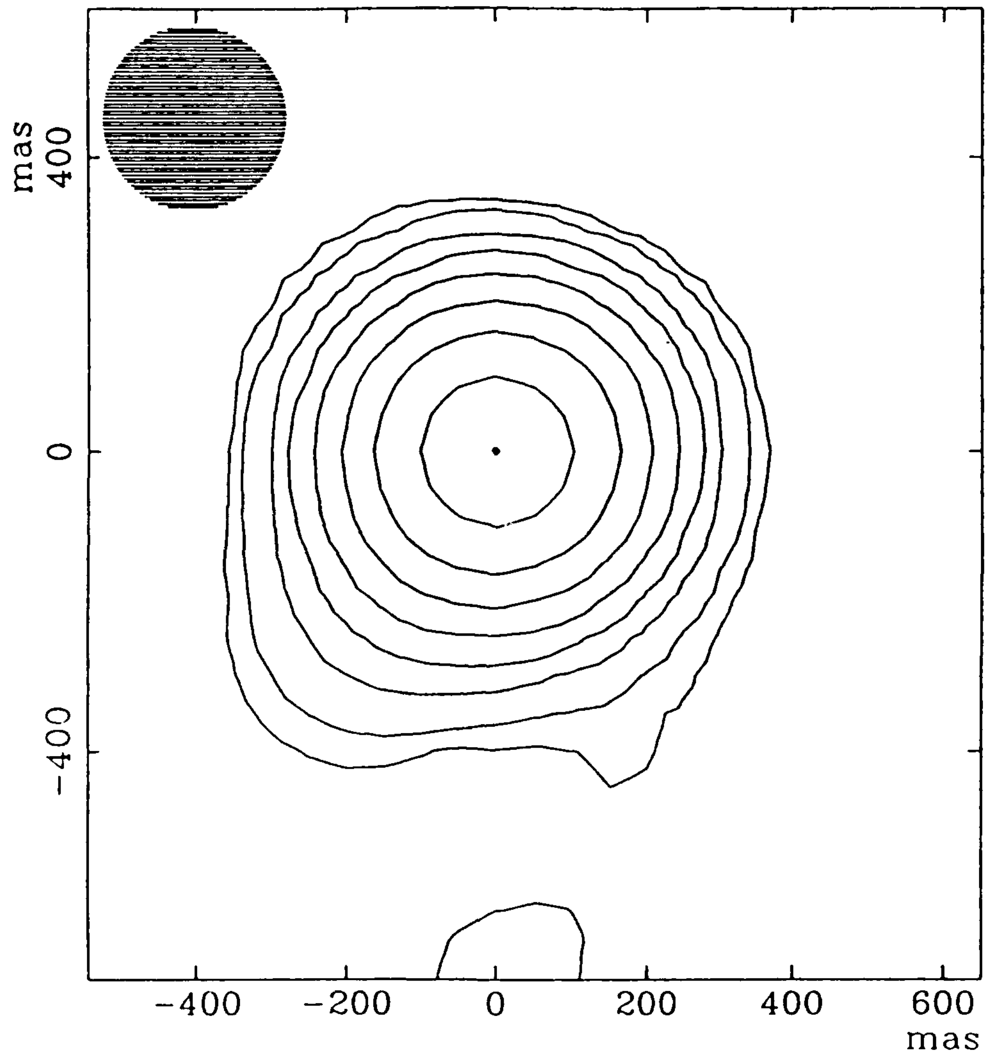

Figure 2

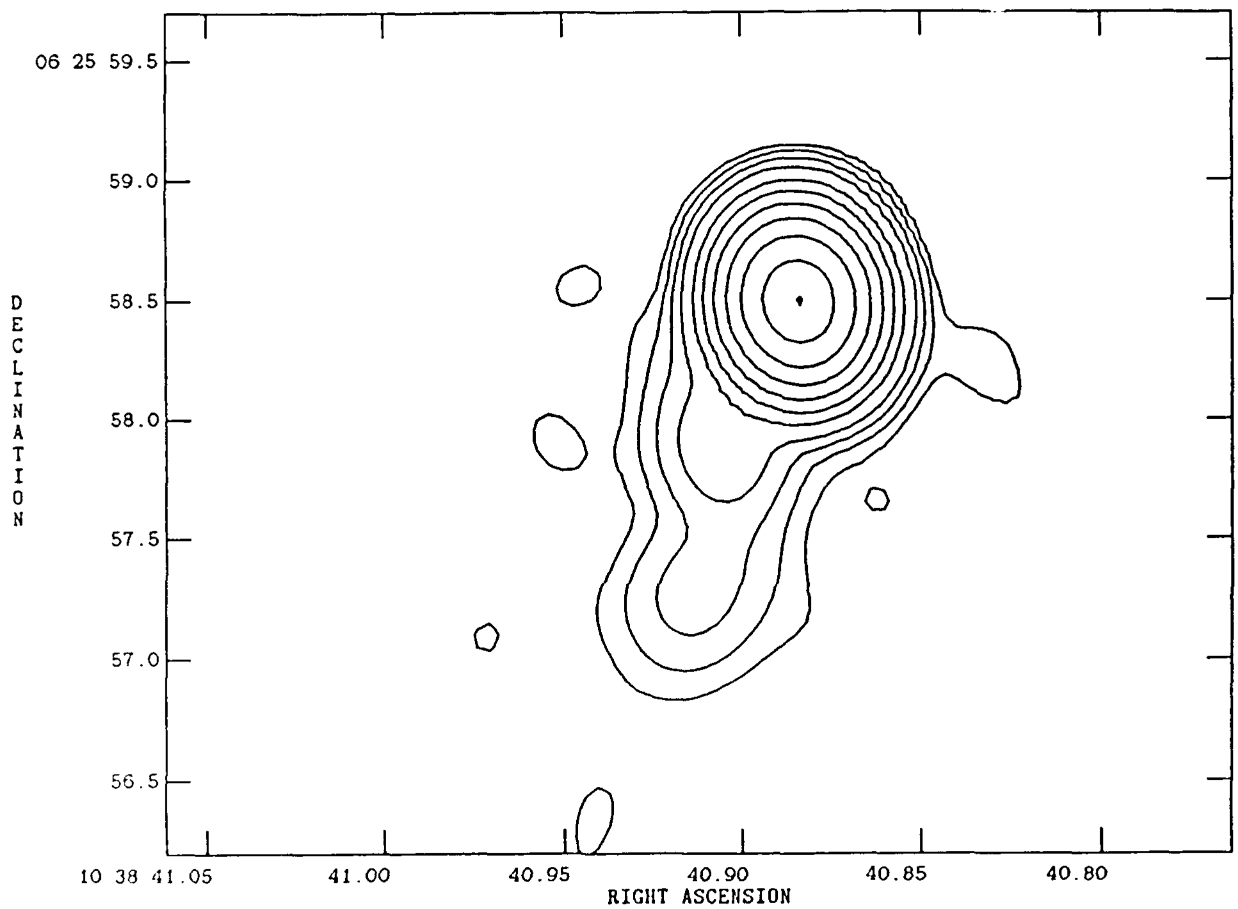
06 25 59.5
59.0
58.5
58.0
57.5
57.0
56.5
DECLINATION
10 38 41.05
41.00
40.95
40.90
40.85
40.80
RIGHT ASCENSION

Figure 3

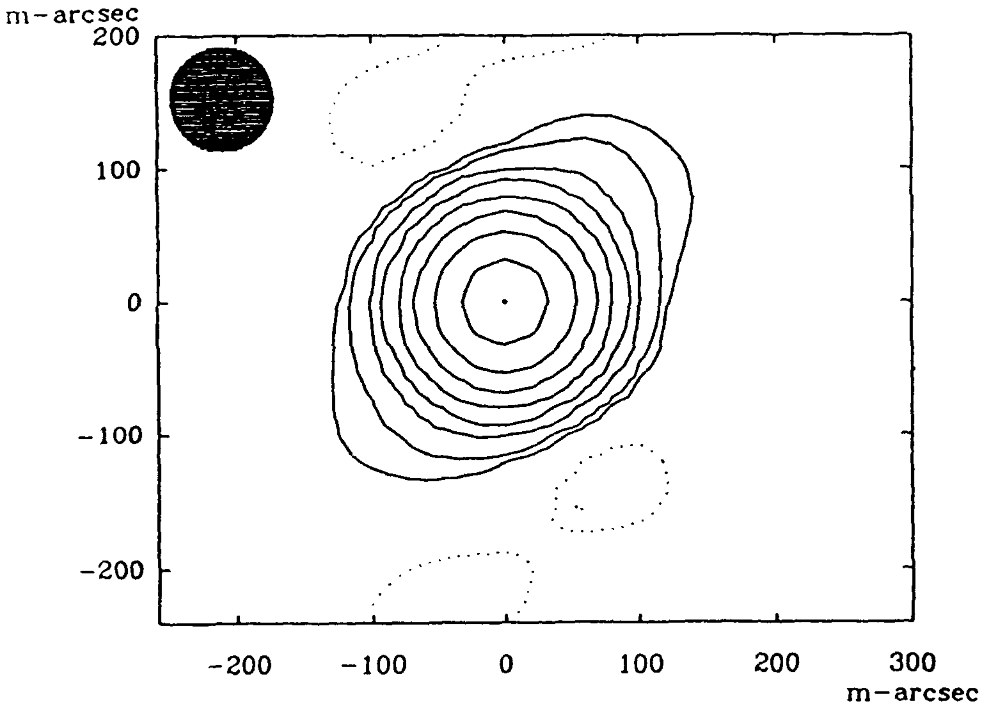

Figure 4

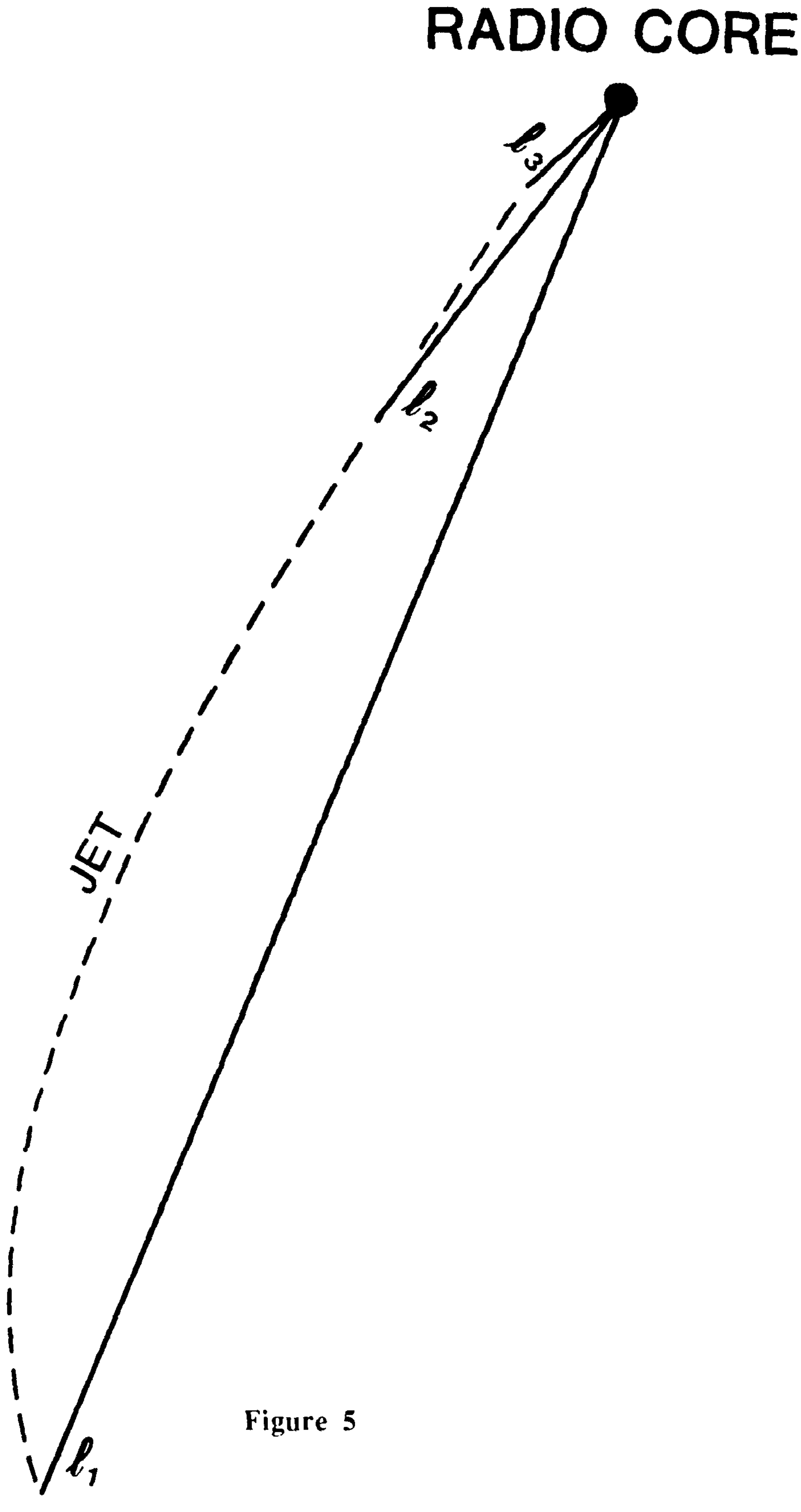

Figure 5

Jet Length vs. Position Angle

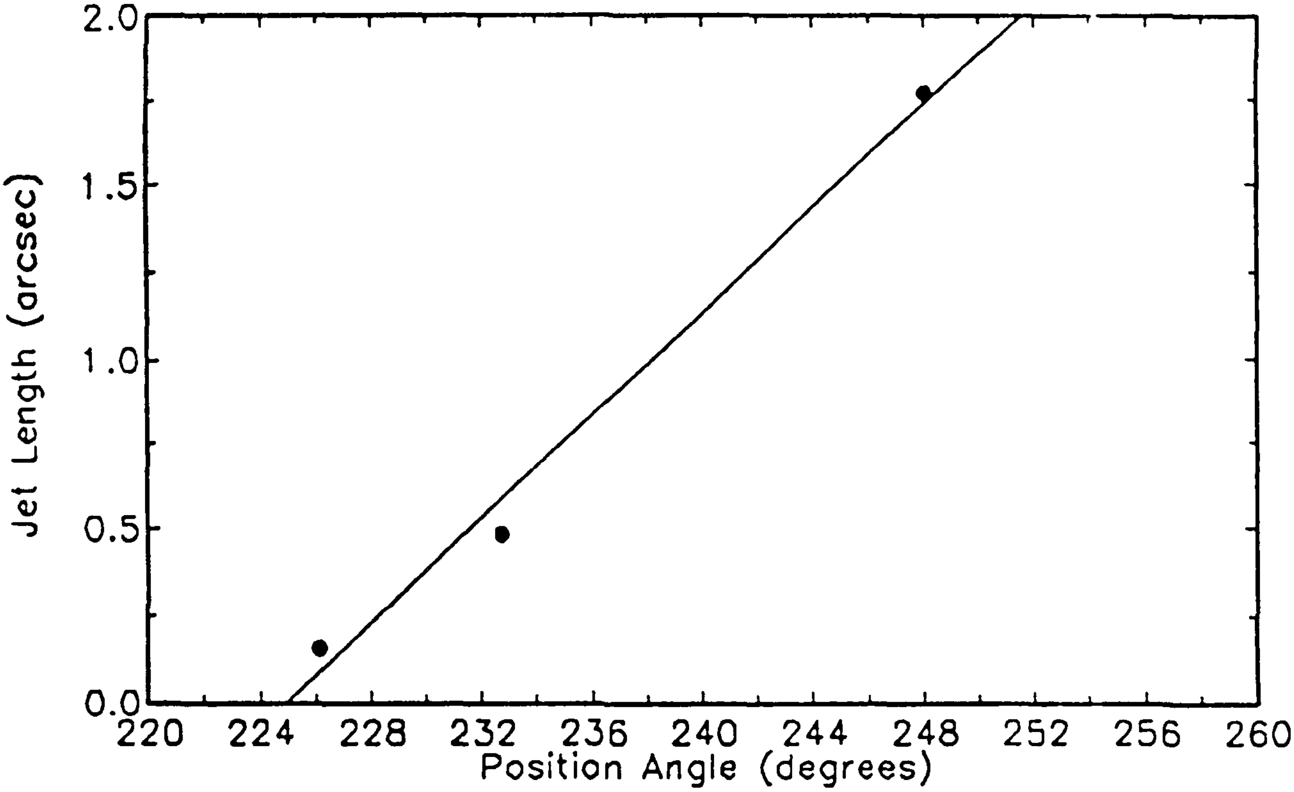

Figure 6

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Theory of the Anisotropic Ferrite Wakefield Accelerator

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Abstract

The theory of the anisotropic ferrite wakefield accelerator is solved wherein the ferrite is driven into saturation by a static magnetic field resulting in a permeability tensor having off-diagonal elements. We show that it is possible to obtain a maximum accelerating gradient of 1.5 megavolts per meter per nanoCoulomb of driver beam charge for a driver beam of 0.7 millimeters rms bunch length. This compares favorably with wakefield accelerators based upon other types of structures.

I. Introduction

It is clear that in the near future, a new technology will be needed for building high energy accelerators. If one considers the case of linear electron accelerators, the most powerful of its kind in existence today is located at the Stanford Linear Accelerator Center (SLAC). In the SLAC machine, electrons are accelerated up to 50 GeV over a distance of 2 miles, thus yielding accelerating gradients of about 15 MV/m. If one ever hopes to build TeV electron colliders, certainly it would be advantageous to have in place some technology yielding in excess of 100 MV/m.

One such method which has received considerable attention is called wakefield acceleration. In this scheme, an intense bunch of electrons called the driver beam traverses some medium or structure, giving up part of its energy to the electromagnetic field in its wake. Subsequently, a second dilute bunch of electrons called the witness beam travels through

the same medium or structure, and is thus accelerated by the driver's electromagnetic wakefield.

The most promising medium to be considered in wakefield acceleration studies was that of a dense plasma which could yield accelerating gradients in excess of lGV/m. First proposed by Ya. Feinberg,[1,2] it was subsequently studied by B. Bolotovsky,[3] and in recent times it has gained renewed interest due to the work of J. Dawson and collaborators.[4]. The experimental verification of plasma wakefield acceleration for modest acceleration gradients was provided by J. Simpson, J. Rosenzweig, and collaborators.[5] Similar experiments are presently under consideration to be done in the near future by A. Amatuni and co-workers.[6]

J. Simpson et al.[7] have recently pointed out that a variety of technical problems associated with plasma wakefield acceleration may prove difficult to overcome in trying to build practical accelerators based upon this technique. Nonlinearities in the plasma are poorly understood, although the problem has begun to be explored both theoretically and experimentally.[8-11] But perhaps the most difficult problem has to do with transverse forces in the plasma wakefield which make it difficult to control the trajectory of particles within the witness pulse as a result of their alignment errors.

As for structures, J. Simpson et al. have theoretically and experimentally studied wakefield acceleration in pillbox cavities.[12] Here again transverse forces are a major problem, leading to beam instabilities even within the driver bunch.

More recently, wakefield acceleration using a metal tube lined with a dielectric material has been proposed.[13] In this scheme the transverse forces are not quite so bad as they are in the plasmas and pillbox cavities, but they still present a problem.[14-16] The experimental verification of this technique has been provided recently.[17]

In the present work we explore another structure, a metal tube lined with some ferrite material with a static magnetic field applied along the longitudinal direction. For that reason it is called the anisotropic ferrite wakefield accelerator. Throughout the discussions we use the mks system of units. Previous work on wakefields in magnetized ferrite-lined tubes has been carried out by N. Nasonov et al. in the context of the self-acceleration of electron bunches.[18-23]

In the next section we derive the electromagnetic fields inside the ferrite. In Section III we solve for the electromagnetic fields inside the vacuum hole. In Section IV we apply the boundary conditions and solve for the coefficients of the homogeneous electromagnetic field solutions. Finally, in Section V we offer an example and concluding remarks.

II. Field Solutions Inside the Ferrite

A. The Permeability Tensor

Using the Gilbert form[24] of the dynamical equation governing the magnetization vector, we can write

$$\frac{d\mathbf{M}}{dt} = \Gamma_e(\mathbf{M} \times \mathbf{H}) + \frac{\alpha}{M}\mathbf{M} \times \frac{d\mathbf{M}}{dt}, \tag{1}$$

where $\mathbf{M}$ is the magnetization vector with magnitude M, $\mathbf{H}$ is the magnetic field, α is the damping parameter, and Γ_e is the gyromagnetic ratio given by

$$\Gamma_e = -g(\mu_0 e/2m_e)$$

with e and m_e being the charge and mass of the electron, μ_0 the permeability of free space, and g the spectroscopic splitting factor. Since $g = 2$ for a free electron, in our case $\Gamma_e = -2.21 \times 10^5$ (rad/sec)/(Amp-turns/meter).

Next, we can write

$$\mathbf{H} \;=\; H_s\hat{k} + \mathbf{H}_{rf}(t) - D \cdot \mathbf{M} \tag{2}$$

$$\mathbf{M} \;=\; M_s\hat{k} + \mathbf{M}_{rf}(t), \tag{3}$$

where the subscripts s and rf refer to the static and oscillatory parts of the fields, $\hat{k}$ is the unit vector along the longitudinal direction, and the tensor D is the demagnetization factor which can be neglected throughout our discussions since they are automatically included when we impose boundary conditions on the fields.[25] In Cartesian coordinates we have

$$\mathbf{H}_{rf}(t) \;=\; (H_x\hat{i} + H_y\hat{j} + H_z\hat{k})e^{i\omega t} \tag{4}$$

$$\mathbf{M}_{rf}(t) = (M_x\hat{i} + M_y\hat{j} + M_z\hat{k})e^{i\omega t}, \quad (5)$$

where ω is the angular frequency. We make the assumption that

$$\mid \mathbf{H}_{rf} \mid << H_s \quad (6)$$

$$\mid \mathbf{M}_{rf} \mid << M_s. \quad (7)$$

To obtain the magnetic susceptibility of the ferrite, we substitute the expressions for **H** and **M** in Eqs. (2)-(5) into Eq. (1) and obtain

$$M_x = \frac{\Gamma_e M_s(\Gamma_e H_s - i\omega\alpha)}{(\omega_r + i\omega\alpha)^2 - \omega^2} H_x - \frac{i\omega\Gamma_e M_s}{(\omega_r + i\omega\alpha)^2 - \omega^2} H_y \quad (8)$$

$$M_y = \frac{i\omega\Gamma_e M_s}{(\omega_r + i\omega\alpha)^2 - \omega^2} H_x + \frac{\Gamma_e M_s(\Gamma_e H_s - i\omega\alpha)}{(\omega_r + i\omega\alpha)^2 - \omega^2} H_y \quad (9)$$

$$M_z = 0, \quad (10)$$

where $\omega_r = -\Gamma_e H_s$ is the ferrite resonance frequency. In matrix form, Eqs. (8)-(10) become

$$\begin{pmatrix} M_x \\ M_y \\ M_z \end{pmatrix} = \begin{pmatrix} \chi & -iK & 0 \\ iK & \chi & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} H_x \\ H_y \\ H_z \end{pmatrix}. \quad (11)$$

If we define

$$\chi = \chi' - i\chi'' \quad (12)$$

$$K = K' - iK'' \quad (13)$$

$$\omega_m = -\Gamma_e M_s, \quad (14)$$

where χ and K have been divided into real and imaginary parts, then we can write

$$\chi' = \frac{\omega_m \omega_r(\omega_r^2 - \omega^2) + \omega_m \omega_r \alpha^2 \omega^2}{[\omega_r^2 - \omega^2(1+\alpha^2)]^2 + 4\omega^2 \omega_r^2 \alpha^2} \tag{15}$$

$$\chi'' = \frac{\omega_m \omega \alpha[\omega_r^2 + (1+\alpha^2)\omega^2]}{[\omega_r^2 - \omega^2(1+\alpha^2)]^2 + 4\omega^2 \omega_r^2 \alpha^2} \tag{16}$$

$$K' = \frac{-\omega_m \omega[\omega_r^2 - \omega^2(1+\alpha^2)]}{[\omega_r^2 - \omega^2(1+\alpha^2)]^2 + 4\omega^2 \omega_r^2 \alpha^2} \tag{17}$$

$$K'' = \frac{-2\omega_m \omega_r \omega^2 \alpha}{[\omega_r^2 - \omega^2(1+\alpha^2)]^2 + 4\omega^2 \omega_r^2 \alpha^2}. \tag{18}$$

In our application of a ferrite-lined metallic tube, it is convenient to use cylindrical coordinates and it is straightforward to show

$$\chi_{rr} = \chi_{\theta\theta} = \chi_{xx} = \chi_{yy} \tag{19}$$

$$\chi_{r\theta} = \chi_{xy} = -\chi_{\theta r} = -\chi_{yx}. \tag{20}$$

From the susceptibility tensor χ defined by Eq. (11), the permeability tensor μ is

$$\mu = \mu_0(I + \chi) \equiv \mu_0 \mu_r \quad \text{with} \tag{21}$$

$$\mathbf{B} = \mu \cdot \mathbf{H}, \tag{22}$$

where I is the identity matrix and μ_r is the relative permeability and can be written

$$\mu_r = \begin{pmatrix} \tilde{\mu} = 1 + \chi_{rr} & -iK & 0 \\ iK & \tilde{\mu} & 0 \\ 0 & 0 & \tilde{\mu}_z \end{pmatrix}. \tag{23}$$

Now that we have the permeability tensor inside the ferrite medium, let us next solve Maxwell's equations inside the ferrite.

B. Solutions to Maxwell's Equations

Consider a metallic tube lined with a ferrite material as shown in Fig. 1. The ferrite is contained in the region $a \leq r \leq b$, where r is the radial coordinate. Maxwell's Equations inside the ferrite are given by

$$\nabla \times \mathbf{E}^f = -\frac{\partial \mathbf{B}^f}{\partial t} \tag{24}$$

$$\nabla \times \mathbf{H}^f = \frac{\partial \mathbf{D}^f}{\partial t} \tag{25}$$

$$\nabla \cdot \mathbf{D}^f = 0 \tag{26}$$

$$\nabla \cdot \mathbf{B}^f = 0, \tag{27}$$

with the constitutive equations

$$\mathbf{D}^f = \epsilon_f \mathbf{E}^f \tag{28}$$

$$\mathbf{B}^f = \mu_0 \mu_r \cdot \mathbf{H}^f. \tag{29}$$

Assuming all oscillatory fields vary as $e^{-kz+i\omega t}$, then the curl equations in cylindrical coordinates for the time-dependent fields become[25]

$$\frac{1}{r}\frac{\partial E_z^f}{\partial \theta} + \kappa E_\theta^f = -i\omega\mu_0(\tilde{\mu} H_r^f - iK H_\theta^f) \tag{30}$$

$$-\kappa E_r^f - \frac{\partial E_z^f}{\partial r} = -i\omega\mu_o(iK H_r^f + \tilde{\mu} H_\theta^f) \tag{31}$$

$$\frac{1}{r}\left[\frac{\partial(rE^f_\theta)}{\partial r} - \frac{\partial E^f_r}{\partial\theta}\right] = -i\omega\mu_0\tilde{\mu}_z H^f_z \tag{32}$$

$$\frac{1}{r}\frac{\partial H^f_z}{\partial\theta} + \kappa H^f_\theta = i\omega\epsilon_f E^f_r \tag{33}$$

$$-\kappa H^f_r - \frac{\partial H^f_z}{\partial r} = i\omega\epsilon_f E^f_\theta \tag{34}$$

$$\frac{1}{r}\left[\frac{\partial(rH^f_\theta)}{\partial r} - \frac{\partial H^f_r}{\partial\theta}\right] = i\omega\epsilon_f E^f_z. \tag{35}$$

Since Eqs. (30), (31), (33), and (34) do not contain derivatives of the transverse field components, we can solve for those transverse components in terms of the derivatives of E^f_z and H^f_z One gets

$$E^f_r = p^f\frac{\partial E^f_z}{\partial r} + q^f\frac{1}{r}\frac{\partial E^f_z}{\partial\theta} + r^f\frac{\partial H^f_z}{\partial r} + s^f\frac{1}{r}\frac{\partial H^f_z}{\partial\theta} \tag{36}$$

$$E^f_\theta = -q^f\frac{\partial E^f_z}{\partial r} + p^f\frac{1}{r}\frac{\partial E^f_z}{\partial\theta} - s^f\frac{\partial H^f_z}{\partial r} + r^f\frac{1}{r}\frac{\partial H^f_z}{\partial\theta} \tag{37}$$

$$H^f_r = t^f\frac{\partial E^f_z}{\partial r} + u^f\frac{1}{r}\frac{\partial E^f_z}{\partial\theta} + p^f\frac{\partial H^f_z}{\partial r} + q^f\frac{1}{r}\frac{\partial H^f_z}{\partial\theta} \tag{38}$$

$$H^f_\theta = -u^f\frac{\partial E^f_z}{\partial r} + t^f\frac{1}{r}\frac{\partial E^f_z}{\partial\theta} - q^f\frac{\partial H^f_z}{\partial r} + p^f\frac{1}{r}\frac{\partial H^f_z}{\partial\theta}, \tag{39}$$

where

$$p^f = -\kappa(\kappa^2 + \omega^2\epsilon_f\mu_0\tilde{\mu})(\Delta^f)^{-1} \tag{40}$$

$$q^f = -i\kappa\omega^2\epsilon_f\mu_0 K(\Delta^f)^{-1} \tag{41}$$

$$r^f = \omega\mu_0 K\kappa^2(\Delta^f)^{-1} \tag{42}$$

$$s^f = -i\omega[\mu_0\tilde{\mu}\kappa^2 + \omega^2\mu_0^2(\tilde{\mu}^2 - K^2)\epsilon_f](\Delta^f)^{-1} \tag{43}$$

$$t^f = \omega^3\epsilon_f^2\mu_0 K(\Delta^f)^{-1} \tag{44}$$

$$u^f = i\omega(\epsilon_f\kappa^2 + \omega^2\epsilon_f^2\mu_0\tilde{\mu})(\Delta^f)^{-1} \tag{45}$$

$$\Delta^f = [\kappa^2 + \omega^2\epsilon_f\mu_0(\tilde{\mu} + K)][\kappa^2 + \omega^2\epsilon_f\mu_0(\tilde{\mu} - K)] \tag{46}$$

Upon substituting these expressions for the transverse fields back into Eqs. (32) and (35), one gets

$$\nabla^2_{r,\theta} E^f_z + aE^f_z + bH^f_z = 0 \tag{47}$$

$$\nabla^2_{r,\theta} H^f_z + cH^f_z + dE^f_z = 0, \tag{48}$$

where

$$a = \kappa^2 + \omega^2 \epsilon_f \mu_0 \frac{(\tilde{\mu}^2 - K^2)}{\tilde{\mu}} \tag{49}$$

$$b = \frac{\kappa\omega\mu_0\tilde{\mu}_z K}{\tilde{\mu}} \tag{50}$$

$$c = \frac{\tilde{\mu}_z}{\tilde{\mu}}(\kappa^2 + \omega^2 \epsilon_f \mu_0 \tilde{\mu}) \tag{51}$$

$$d = -\frac{\kappa K \omega \epsilon_f}{\tilde{\mu}}. \tag{52}$$

It is important to note that if either E_z or H_z is equal to zero, then all oscillatory fields vanish. Therefore, there are no pure TE or TM modes. This is due to the anisotropy of the d-c magnetized ferrite medium. Thus, if one were to turn off H_s, then the off-diagonal components of the permeability tensor K would be zero and one would retrieve the usual TE and TM modes propagating through the structure.

In order to solve Eqs. (47) and (48), we introduce functions F_1 and F_2 and parameters g_1 and g_2 such that

$$E_z = F_1 + F_2 \tag{53}$$

$$H_z = g_1 F_1 + g_2 F_2 \tag{54}$$

$$g_1 \neq g_2. \tag{55}$$

Upon substituting Eqs. (53) and (54) into Eqs. (47) and (48) we arrive at

$$\nabla^2_{r,\theta} F_1 + (a + bg_1)F_1 + \nabla^2_{r,\theta} F_2 + (a + bg_2)F_2 = 0 \tag{56}$$

$$g_1 \nabla^2_{r,\theta} F_1 + (d + cg_1)F_1 + g_2 \nabla^2_{r,\theta} F_2 + (d + cg_2)F_2 = 0. \tag{57}$$

If it is possible to determine g_1 and g_2 such that

$$a + bg_1 = k_1^2, \qquad a + bg_2 = k_2^2 \tag{58}$$

$$d + cg_1 = g_1 k_1^2, \qquad d + cg_2 = g_2 k_2^2. \tag{59}$$

Then

$$\nabla_{r,\theta}^2 F_1 + k_1^2 F_1 + \nabla_{r,\theta}^2 F_2 + k_2^2 F_2 = 0 \tag{60}$$

$$g_1(\nabla_{r,\theta}^2 F_1 + k_1^2 F_1) + g_2(\nabla_{r,\theta}^2 F_2 + k_2^2 F_2) = 0. \tag{61}$$

But since $g_1 \neq g_2$ then it follows that

$$\nabla_{r,\theta}^2 F_1 + k_1^2 F_1 = 0 \tag{62}$$

$$\nabla_{r,\theta}^2 F_2 + k_2^2 F_2 = 0, \tag{63}$$

where

$$g_1 = \frac{k_1^2 - a}{b} = \frac{d}{k_1^2 - c} \tag{64}$$

$$g_2 = \frac{k_2^2 - a}{b} = \frac{d}{k_2^2 - c}. \tag{65}$$

Also,

$$(k_{1,2}^2 - a)(k_{1,2}^2 - c) = bd \tag{66}$$

so that

$$k_{1,2}^2 = \frac{(a + c) \pm [(a + c)^2 - 4(ac - bd)]^{1/2}}{2}. \tag{67}$$

Finally, we have Eq. (53) together with

$$\begin{aligned} H_z &= \frac{k_1^2 - a}{b} F_1 + \frac{k_2^2 - a}{b} F_2 \\ &= \frac{1}{b}[-a(F_1 + F_2) + k_1^2 F_1 + k_2^2 F_2], \end{aligned} \tag{68}$$

where

$$\begin{aligned} k_{1,2}^2 &= \frac{1}{2}[\kappa^2(1 + \frac{\tilde{\mu}_z}{\tilde{\mu}}) + \omega^2 \mu_0 \epsilon_f \frac{(\tilde{\mu}^2 - K^2)}{\tilde{\mu}} + \omega^2 \epsilon_f \mu_0 \tilde{\mu}_z] \\ &\pm \frac{1}{2}\{[\kappa^2(1 - \frac{\tilde{\mu}_z}{\tilde{\mu}}) + \omega^2 \mu_0 \epsilon_f \frac{(\tilde{\mu}^2 - K^2)}{\tilde{\mu}} - \omega^2 \epsilon_f \mu_0 \tilde{\mu}_z]^2 \\ &-4\kappa^2 \omega^2 \epsilon_f \mu_0 \tilde{\mu}_z (\frac{K}{\tilde{\mu}})^2\}^{1/2} \end{aligned} \tag{69}$$

Now that we know how to write all electromagnetic field components in terms of the functions F_1 and F_2, we next solve Eqs. (62) and (63) for an azimuthally symmetric geometry. This should give the major contribution to the wakefield acceleration. Assuming no θ dependence, Eqs. (62)-(63) become

$$\frac{\partial^2 F_1}{\partial r^2} + \frac{1}{r}\frac{\partial F_1}{\partial r} + k_1^2 F_1 = 0, \tag{70}$$

and similarly for F_2. The solutions inside the ferrite become

$$F_1(r) = A_1 J_0(k_1 r) + B_1 N_0(k_1 r) \tag{71}$$

$$F_2(r) = A_2 J_0(k_2 r) + B_2 N_0(k_2 r), \tag{72}$$

where J_0 and N_0 are the zeroth order Bessel functions of the first and second kinds, respectively.

To derive the longitudinal accelerating field behind the driver electron bunch, we will only need expressions for E_z^f, H_z^f, E_θ^f and H_θ^f . Using Eqs. (37), (39), (53), (54), (71), and (72), we arrive at

$$
\begin{aligned}
E_z^f &= \{A_1 J_0(k_1 r) + A_2 J_0(k_2 r) + B_1 N_0(k_1 r) + B_2 N_0(k_2 r)\} e^{-\kappa z + i\omega t} && (73)\\
H_z^f &= \frac{\tilde{\mu}}{\kappa\omega\mu_0\tilde{\mu}_z K}\{[k_1^2 - \kappa^2 - \omega^2 \epsilon_f \mu_0 \frac{(\tilde{\mu}^2 - K^2)}{\tilde{\mu}}][A_1 J_0(k_1 r) + B_1 N_0(k_1 r)] \\
&\quad + [k_2^2 - \kappa^2 - \omega^2 \epsilon_f \mu_0 \frac{(\tilde{\mu}^2 - K^2)}{\tilde{\mu}}][A_2 J_0(k_2 r) + B_2 N_0(k_2 r)]\} e^{-\kappa z + i\omega t} && (74)\\
E_\theta^f &= i\kappa\omega^2 \epsilon_f \mu_0 K \Delta^{-1} \{k_1[A_1 J_0'(k_1 r) + B_1 N_0'(k_1 r)] \\
&\quad + k_2[A_2 J_0'(k_2 r) + B_2 N_0'(k_2 r)]\} e^{-\kappa z + i\omega t} \\
&\quad + \frac{i\tilde{\mu}}{\kappa\mu_0\tilde{\mu}_z K}[\mu_0\tilde{\mu}\kappa^2 + \omega^2 \mu_0^2 (\tilde{\mu}^2 - K^2)\epsilon_f]\Delta^{-1} \\
&\quad \cdot \{[k_1^2 - \kappa^2 - \omega^2 \epsilon_f \mu_0 \frac{(\tilde{\mu}^2 - K^2)}{\tilde{\mu}}][k_1(A_1 J_0'(k_1 r) + B_1 N_0'(k_1 r))] \\
&\quad + [k_2^2 - \kappa^2 - \omega^2 \epsilon_f \mu_0 \frac{(\tilde{\mu}^2 - K^2)}{\tilde{\mu}}][k_2(A_2 J_0'(k_2 r) + B_2 N_0'(k_2 r))]\} e^{-\kappa z + i\omega t} && (75)\\
H_\theta^f &= -i\omega(\epsilon_f \kappa^2 + \omega^2 \epsilon_f^2 \mu_0 \tilde{\mu})\Delta^{-1} \{k_1[A_1 J_0'(k_1 r) + B_1 N_0'(k_1 r)] \\
&\quad + k_2[A_2 J_0'(k_2 r) + B_2 N_0'(k_2 r)]\} e^{-\kappa z + i\omega t} \\
&\quad + \frac{i\omega\epsilon_f \tilde{\mu}\Delta^{-1}}{\tilde{\mu}_z}\{[k_1^2 - \kappa^2 - \omega^2 \epsilon_f \mu_0 \frac{(\tilde{\mu}^2 - K^2)}{\tilde{\mu}}][k_1(A_1 J_0'(k_1 r) + B_1 N_0'(k_1 r))] \\
&\quad + [k_2^2 - \kappa^2 - \omega^2 \epsilon_f \mu_0 \frac{(\tilde{\mu}^2 - K^2)}{\tilde{\mu}}][k_2(A_2 J_0'(k_2 r) + B_2 N_0'(k_2 r))]\} e^{-\kappa z + i\omega t}. && (76)
\end{aligned}
$$

We now have expressions for the field solutions inside the ferrite medium. The constants A_1, B_1, A_2, and B_2 will be determined later by the boundary conditions. In the next section we proceed to solve for the fields inside the vacuum hole.

III. Field Solutions Inside the Vacuum Hole

Inside the vacuum hole, Maxwell's Equations become

$$
\begin{aligned}
\nabla \times \mathbf{E}^{h} &= -\frac{\partial \mathbf{B}^{h}}{\partial t} && (77)\\
\nabla \times \mathbf{H}^{h} &= \mathbf{J} + \frac{\partial \mathbf{D}^{h}}{\partial t} && (78)\\
\nabla \cdot \mathbf{E}^{h} &= \frac{\rho}{\epsilon_0} && (79)\\
\nabla \cdot \mathbf{B}^{h} &= 0, && (80)
\end{aligned}
$$

with the constitutive equations

$$
\begin{aligned}
\mathbf{D}^{h} &= \epsilon_0 \mathbf{E}^{h} && (81)\\
\mathbf{B}^{h} &= \mu_0 \mathbf{H}^{h}. && (82)
\end{aligned}
$$

We follow a similar procedure as in Section II, although it is simpler in this case. We first solve for the longitudinal components E_z^h, H_z^h which satisfy

$$
[\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}] \begin{pmatrix} E_z^h \\ H_z^h \end{pmatrix} = \begin{pmatrix} \frac{1}{\epsilon_0}\frac{\partial \rho}{\partial z} + \mu_0 \frac{\partial J_z}{\partial t} \\ 0 \end{pmatrix}. \qquad (83)
$$

We consider the case where the driver is a line of charge having a Gaussian line distribution. So we have

$$
\begin{aligned}
\rho(z - vt, r) &= -\frac{Q}{(2\pi)^{1/2}} \frac{\delta(r)}{r\sigma_z} e^{-(z-vt)^2/2\sigma_z^2} && (84)\\
\mathbf{J}(z - vt, r) &= \rho \mathbf{v} = (0, 0, \rho v), && (85)
\end{aligned}
$$

where Q is the charge in the driver electron bunch, σ_z is the rms bunch length, and $\upsilon = \beta c$ is the speed of the driver, with $c^2 = \frac{1}{\mu_0 \varepsilon_0}$.

Expanding E_z^h and ρ in harmonics

$$E_z^h(z - vt, r) = \int_{-\infty}^{\infty} e^{-\frac{i\omega}{v}(z-vt)} E_z^h(\omega, r) d\omega \tag{86}$$

$$\rho(z - vt, r) = \int_{-\infty}^{\infty} e^{-\frac{i\omega}{v}(z-vt)} \rho(\omega, r) d\omega \tag{87}$$

we get

$$\rho(\omega, r) = -\frac{Q}{4\pi^2} \frac{\delta(r)}{rv} e^{-\frac{\omega^2 \sigma_z^2}{2v^2}} \tag{88}$$

and Eq. (83) becomes

$$[\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial}{\partial r}) - \frac{\omega^2}{v^2}(1 - \beta^2)]E_z^h(\omega, r) = \frac{iQ\omega}{(2\pi)^{3/2}\epsilon_0 v^2 \gamma^2} \frac{\delta(r)}{r\sigma_z} f(\omega) \tag{89}$$

having the solution

$$E_z^h(\omega, r) = \frac{-iQ\omega}{4\pi^2 \epsilon_0 v^2 \gamma^2} e^{-\frac{\omega^2 \sigma_z^2}{2v^2}} K_0(\frac{\omega r}{v}\sqrt{1 - \beta^2}) + C I_0(\frac{\omega r}{v}\sqrt{1 - \beta^2}), \tag{90}$$

where γ is the Lorentz contraction factor and I_0 and K_0 are the zeroth order modified Bessel functions. Similarly, for H_z^h we obtain

$$H_z^h(\omega, r) = G I_0(\frac{\omega r}{v}\sqrt{1 - \beta^2}). \tag{91}$$

where the constants C and G will be determined in the next section by the boundary conditions.

Following the procedure outlined in Section III, but specialized to the vacuum, we obtain for the transverse fields

$$E_r^h = \frac{iv\gamma^2}{\omega} \frac{\partial E_z}{\partial r} + \frac{i\mu_0 v^2 \gamma^2}{\omega r} \frac{\partial H_z^h}{\partial \theta} \tag{92}$$

$$E_\theta^h = \frac{iv\gamma^2}{\omega r} \frac{\partial E_z^h}{\partial \theta} - \frac{i\mu_0 v^2 \gamma^2}{\omega} \frac{\partial H_z^h}{\partial r} \tag{93}$$

$$H_r^h = \frac{-i\epsilon_0 v^2 \gamma^2}{\omega r} \frac{\partial E_z^h}{\partial \theta} + \frac{iv\gamma^2}{\omega} \frac{\partial H_z^h}{\partial r} \tag{94}$$

$$H_\theta^h = \frac{i\epsilon_0 v^2 \gamma^2}{\omega} \frac{\partial E_z^h}{\partial r} + \frac{iv\gamma^2}{\omega r} \frac{\partial H_z^h}{\partial \theta} \tag{95}$$

Using Eqs. (90)-(95) and assuming no θ dependence for the fields we finally obtain

$$
\begin{aligned}
E_z^h(\omega,r) &= \frac{-iQ\omega}{4\pi^2\epsilon_0 v^2\gamma^2}e^{-\frac{\omega^2\sigma_z^2}{2v^2}}K_0(\frac{\omega r}{v}\sqrt{1-\beta^2}) + CI_0(\frac{\omega r}{v}\sqrt{1-\beta^2}) && (96)\\
E_r^h(\omega,r) &= i\gamma\{\frac{-iQ\omega}{4\pi^2\epsilon_0 v^2\gamma^2}e^{-\frac{\omega^2\sigma_z^2}{2v^2}}K_0'(\frac{\omega r}{v}\sqrt{1-\beta^2}) + CI_0'(\frac{\omega r}{v}\sqrt{1-\beta^2})\} && (97)\\
E_\theta^h(\omega,r) &= -i\mu_0 v\gamma GI_0'(\frac{\omega r}{v}\sqrt{1-\beta^2}) && (98)\\
H_z^h(\omega,r) &= GI_0(\frac{\omega r}{v}\sqrt{1-\beta^2}) && (99)\\
H_r^h(\omega,r) &= i\gamma GI_0'(\frac{\omega r}{v}\sqrt{1-\beta^2}) && (100)\\
H_\theta^h(\omega,r) &= i\epsilon_0 v\gamma\{\frac{-iQ\omega}{4\pi^2\epsilon_0 v^2\gamma^2}e^{-\frac{\omega^2\sigma_z^2}{2v^2}}K_0'(\frac{\omega r}{v}\sqrt{1-\beta^2}) + CI_0'(\frac{\omega r}{v}\sqrt{1-\beta^2})\} && (101)
\end{aligned}
$$

In the next section we apply the boundary conditions to solve for the unknown constants in the field expressions.

IV. Boundary Conditions

Since we have to determine six constants: A_1 B_1, A_2, B_2, C, G, we must impose six boundary conditions. We choose

$$
\begin{aligned}
E_z^f(r=b) &= 0 && (102)\\
E_z^f(r=a) &= E_z^h(r=a) && (103)\\
H_z^f(r=a) &= H_z^h(r=a) && (104)\\
E_\theta^f(r=a) &= E_\theta^h(r=a) && (105)\\
H_\theta^f(r=a) &= H_\theta^h(r=a) && (106)\\
E_\theta^f(r=b) &= 0. && (107)
\end{aligned}
$$

Also, to match the arguments of the exponentials from the ferrite and vacuum regions we must have $\kappa = \frac{i\omega}{\upsilon}$ so that from Eq. (69) we get

$$\begin{aligned} k_{1,2}^2 &= \frac{\omega^2}{2}[-\frac{1}{v^2}(1+\frac{\tilde{\mu}_z}{\tilde{\mu}}) + \mu_0\epsilon_f\frac{(\tilde{\mu}^2 - K^2)}{\tilde{\mu}} + \epsilon_f\mu_0\tilde{\mu}_z] \\ &\pm\frac{\omega^2}{2}\{[-\frac{1}{v^2}(1-\frac{\tilde{\mu}_z}{\tilde{\mu}}) + \mu_0\epsilon_f\frac{(\tilde{\mu}^2 - K^2)}{\tilde{\mu}} - \epsilon_f\mu_0\tilde{\mu}_z]^2 \\ &+4\frac{\epsilon_f}{v^2}\mu_0\tilde{\mu}_z(\frac{K}{\tilde{\mu}})^2\}^{1/2}. \end{aligned} \quad (108)$$

Eqs. (102)-(107) can be written in the form

$$MX = Y. \quad (109)$$

where

$$M = \begin{pmatrix} \alpha_1 & \beta_1 & \delta_1 & \gamma_1 & 0 & 0 \\ \alpha_2 & \beta_2 & \delta_2 & \gamma_2 & \nu_2 & 0 \\ \alpha_3 & \beta_3 & \delta_3 & \gamma_3 & 0 & \lambda_3 \\ \alpha_4 & \beta_4 & \delta_4 & \gamma_4 & 0 & \lambda_4 \\ \alpha_5 & \beta_5 & \delta_5 & \gamma_5 & \nu_5 & 0 \\ \alpha_6 & \beta_6 & \delta_6 & \gamma_6 & 0 & 0 \end{pmatrix} \quad (110)$$

$$X = \begin{pmatrix} A_1 \\ B_1 \\ A_2 \\ B_2 \\ C \\ G \end{pmatrix}, \qquad Y = \begin{pmatrix} 0 \\ d_2 \\ 0 \\ 0 \\ d_5 \\ 0 \end{pmatrix}. \quad (111)$$

To find the accelerating field E_z^h inside the vacuum hole, we need the constant C. Using Cramer's Rule[26] for solving simultaneous linear equations we find

$$C = \frac{det\ M(\nu_i \to d_i)}{det\ M}, \tag{112}$$

where in the numerator we mean to replace the coefficients υ_i by the quantities d_i Thus, for the accelerating wakefield, we obtain

$$\begin{aligned} E_z^h(z - vt, r) &= \int_{-\infty}^{\infty} e^{-\frac{i\omega}{v}(z-vt)}[\frac{det\ M(\nu_i \to d_i)}{det\ M} I_0(\frac{\omega r}{v}\sqrt{1-\beta^2}) \\ &- \frac{iQ\omega}{4\pi^2\epsilon_0 v^2\gamma^2} e^{-\frac{\omega^2\sigma_z^2}{2v^2}} K_0(\frac{\omega r}{v}\sqrt{1-\beta^2})]\ d\omega. \end{aligned} \tag{113}$$

Since the second term can be neglected relative to the first, we have finally

$$E_z^h(z - vt, r) = \int_{-\infty}^{\infty} e^{-\frac{i\omega}{v}(z-vt)} \frac{det\ M(\nu_i \to d_i)}{det\ M} I_0(\frac{\omega r}{v}\sqrt{1-\beta^2})\ d\omega. \tag{114}$$

The coefficient C and the expression for $E_z^h(z - \upsilon t, r)$ can be evaluated on the computer by summing the residues of the poles in the frequency complex plane. The results for a specific example are discussed in the next section.

V. Discussion and Conclusions

As an example of an anisotropic ferrite wakefield accelerator, we consider the following per one nanoCoulomb of driver charge:

rms length of driver bunch $\sigma_z = 0.7$ mm (115)

Energy of driver bunch = 150 MeV ($\beta = 0.999994$) (116)

Inner ferrite radius $a = 3$ mm (117)

The inner ferrite radius a is taken as small as possible, provided the driver electron bunch does not scrape the ferrite tube. We take the damping parameter $\alpha = 0$, $\tilde{\mu}_z = 1.0$, and $\varepsilon_f = 10\varepsilon_0$ which for our purposes is the best typical value for ferrites.

Upon varying the parameters: outer ferrite radius b, H_s, and M_s, we obtain the following optimized anisotropic ferrite wakefield accelerator:

$$b = 4 \text{ mm} \tag{118}$$

$$M_s = 10^5 \text{ Ampere-turns/meter} \tag{119}$$

$$H_s = 2.0 \times 10^3 \text{ Ampere-turns/meter} \tag{120}$$

The optimized value of M_s corresponds to a saturated magnetic induction in cgs units of $B_s = 4\pi M_s = 1257$ Gauss, so that it corresponds to realistic ferrite materials.

A graph of E_z^h versus delay behind the driver is shown in Fig. 2. The maximum accelerating gradient is ~ 1.5 MV/m per nanoCoulomb of driver charge. The most important pole contributions in the frequency spectrum are 23.5 Ghz and 66.6 Ghz, while the ferrite resonance frequency is at 70.4 Mhz. Wc have studied damping and found that it has a negligible effect on the above numbers.

We have found that the maximum accelerating gradient is not very sensitive to H_s and M_s, for reasonable values, but likes smaller values of ε_f, however for most ferrites $10\varepsilon_0 \lesssim \varepsilon_f \leq 20\varepsilon_0$. E_z^h increases as a decreases and also increases as the thickness of the ferrite decreases, although as the thickness becomes somewhat less than a millimeter E_z^h starts to drop dramatically.

We can compare the anisotropic ferrite wakefield accelerator with the dielectric wakefield accelerator.[13-16] Considering the same case given in Eqs. (115)-(117), we can optimize in the parameters b and ε_d, where the subscript d corresponds to the dielectric material. The optimal values are

$$b = 4 \text{ mm} \tag{121}$$

$$2\varepsilon_0 \lesssim \varepsilon_d \lesssim 3\varepsilon_0 , \tag{122}$$

where E_z^h attains a maximum value of ~ 2 MV/m per nanoCoulomb of driver charge. This accelerating gradient is comparable to (although somewhat higher) than that of the anisotropic ferrite wakefield accelerator, due mainly to the smallness of ε_d. But since

ferrites and dielectrics give comparable results, the final choice of which material to use will have to be made after further experimental work.

To conclude, we have derived the theory of the anisotropic ferrite wakefield accelerator for the case of azimuthal symmetry and have obtained accelerating gradients of 1.5 MV/m/ nanoCoulomb for realistic ferrite materials and accelerator parameters. By increasing the charge in the driver pulse we should be able to attain accelerating gradients of 100 MV/m. We encourage more work along these lines.

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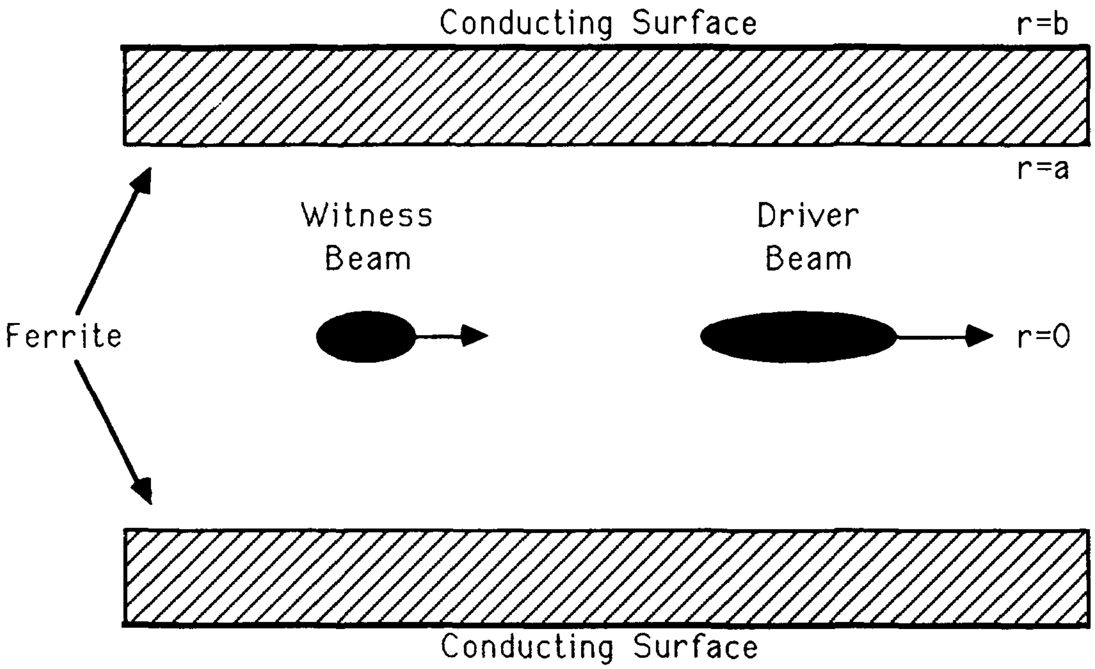

Fig. 1 Ferrite-loaded wakefield structure

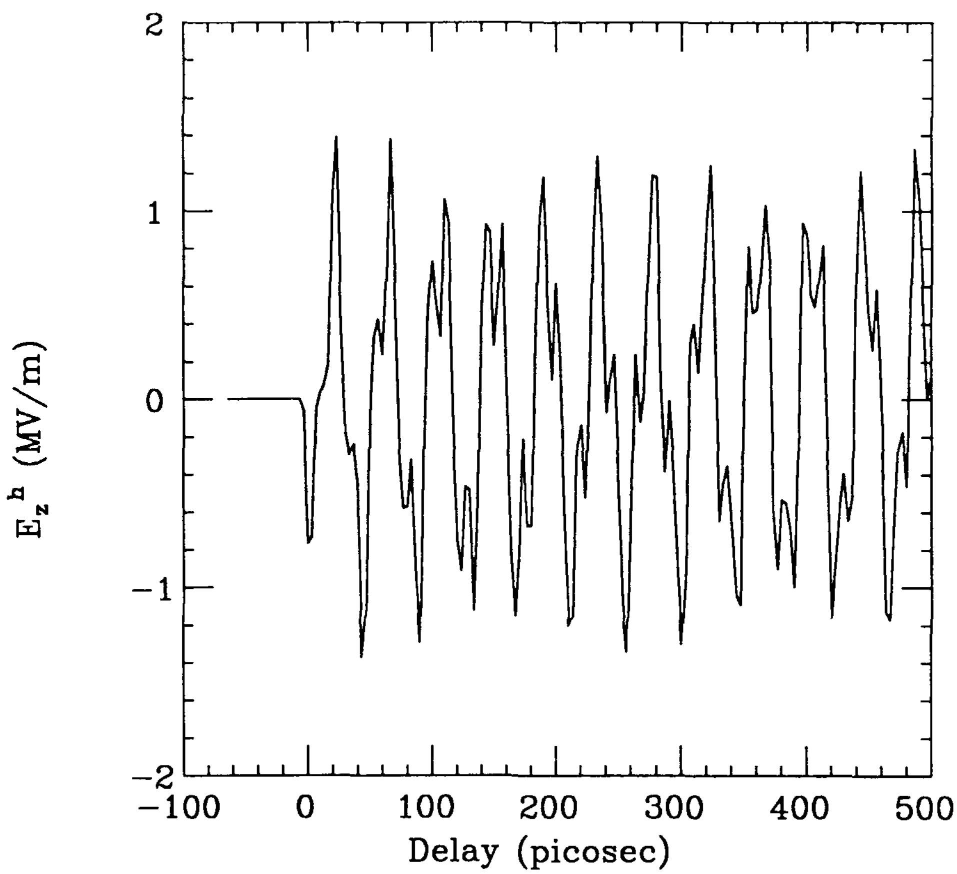

Fig. 2 Accelerating wakefield Ez vs. delay (distance) behind the driver beam for the optimized case: α = 3 mm, b = 4 mm, Q = 1 nC, β = 0.999994, σ_z = 0.7 mm, α = 0, $M_s = 10^5$ Amp-turns/m, $H_s = 2 \times 10^3$ Amp-turns/m, $\varepsilon_f = 10\varepsilon_0$.

Professor Charles McGruder, Western Kentucky University (left) and Dr. Larry Madison, LLNL (right)

Absolute Multilayer Characterization at High Spatial Resolution via Real-time Soft X-ray Imaging

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Abstract

An imaging-based technique has been modeled for its suitability and performance in measuring the spatial distribution of the absolute soft x-ray characterization of flat multilayer mirrors. Such a technique, if implemented experimentally, is anticipated to have substantially higher throughput (wafers/day) than is possible from prevailing non-imaging means.

1. Introduction and Motivation

Flat layered synthetic microstructures (LSMs) play a major role in many current experimental campaigns for time- and spatially-resolved soft x-ray spectroscopy. One lesson experimentalists have been learning in fielding these diagnostics is that, for many real-world instruments taking absolute measurements with spatially extended soft x-ray beams, calibrating a multilayer means spatially mapping its rocking curve.

For an arbitrary unknown LSM wafer sample, the d-spacing, peak reflectivity, and angular full-width half max will in general all vary simultaneously over the area, in a way that cannot be known in advance of taking absolute rocking curves. The only correct methodology is to perform an absolute rocking curve measurement at each sample site whose characterization is desired. With the prevailing "single-channel" soft x-ray calibration technique, one scan of the calibration chamber's Θ - 2Θ drive yields up one local rocking curve. For absolute characterization at high spatial resolution (dozens to thousands of sampling sites), such a technique is prohibitively time-consuming.

What is being proposed here is to use the intrinsic parallelism of imaging hardware to record Bragg-diffracted x-ray counts from a large number of LSM sampling sites simultaneously.

The basic idea is as follows. Take the center of the LSM face to be the origin or a Cartesian coordinate system (Figs. 1, 2b). The specular nature of the Bragg-diffraction process determines both the touchdown point (xm, ym, zm) and the local grazing incidence angle of the one ray path from sourcepoint (xS, yS, zS) to detector point (xD, yD, zD), as follows.

Given source-point S of coordinates (xS, yS, zS) and detector point D of coordinates (xD, yD, zD), there is one and only one path for a ray from source point S to bounce off plane y=0 and hit detector point D, while having

incident grazing angle = departing grazing angle.

The exact angle of grazing incidence chosen by the ray path is

$$\theta = \theta(xS, yS, zS, xD, yD, zD) = \arctan\left(\frac{yS + yD}{\sqrt{(xD - xS)^2 + (zD - zS)^2}}\right) \tag{1}$$

The corresponding one and only one point M where this ray touches down is at (xm, 0, zm), where

$$xm = xS + \left(\frac{yS}{yS + yD}\right) * (xD - xS); \tag{2}$$

$$ym = 0; \tag{3}$$

$$zm = zS + \left(\frac{yS}{yS + yD}\right) * (zD - zS); \tag{4}$$

For the same shaft angle θ_{mech}, different points on the LSM face will have different local grazing incidence angles. The finite size of the x-ray source and of each camera pixel causes Bragg-diffraction into each pixel to take place over a small areal range or "footprint" on the LSM surface.

By applying this line of reasoning, one can at each shaft angle θ_{mech}, extract from the image of Bragg-diffracted x-ray counts the local mean grazing incidence angle and local mean reflectivity for each of the LSM sampling sites. From a succession of such discrete

angular stops, one extracts for each LSM sampling site a corresponding succession of ordered pairs (local graz. inc. angle, local mean reflectivity). By traversing any sampling site's recorded list of (local graz. inc. angle, local reflectivity) ordered pairs after the scan is done, one can "play back" that sampling site's absolute local rocking curve.

2. Proposed Experimental Procedure

2.1 Equipment Needed

The chamber layout is sketched in Fig. 1. Baffling (not shown) is such that the x-ray source illuminates the whole LSM piece under test.

- 1 m. diameter x-ray vacuum chamber with high-precision, computer-controllable Θ - 2Θ drive;

- soft x-ray source with demountable anodes (for spectral coverage), small spot size, and of good brightness $\frac{\text{photons}}{\text{sec cm}^2 \text{ [ster] KeV}}$;

- baffling, so that camera elements can only see x-rays that have Bragg-reflected off the LSM surface;

- reference fiducial LSMs for system maintenance and quality control;

- array of position-sensitive soft x-ray detector ("camera"), each of whose elements independently has photon-counting capability;

- color monitor for viewing image accumulations as they occur from camera. This lets operator set source intensity, adjust camera gains and high voltages to good working values before starting a scan. Provides instant visual feedback of progress through a calibration, and also gives a high-resolution, but "raw" and uncorrected real-time look at the LSM under test;

- exposure timer and corresponding mechanical x-ray shutter and any MCP gating electronics, software or manually controllable;

- microcomputer (32-bit, 20 MHz or better) with terminal and
  (1) pair of 16-bit frame-grabber boards;
  (2) sense/actuation connection to the chamber mechanisms and x-ray source shutter;
  (3) numeric coprocessor;
  (4) 40MB HD and diskette drive;

- special image-processing software for incrementally extracting a map of absolute LSM reflectivity from a succession of discrete images;

- source-strength pick-off detector for monitoring the time drift of source intensity during the course of long scans. Monitored by the microcomputer for maintaining absolute normalization of the reflectivity measurement process.

2.2 Proposed Experimental Procedure

(1) Measure and record LSM sample dimensions. Mount and align LSM sample in chamber. Seal chamber and pump down to vacuum. Let x-ray source warm up and stabilize.

(2) Translate LSM sample out the way of beam, swing Θ and 2Θ to both align on 0.0 degrees, staring back at the soft x-ray source. With known, suitable attenuation, accumulate and store a good direct-look normalization image, recording the required accumulation time. Record pick-off detector's reading to correlate for use against possible future source-strength drift as the day goes on.

(3) Decide on a range of shaft angles to scan, and in how many increments to do this.

(4) Translate LSM sample back into the beam path, and set the Θ-2Θ drive to the angles of mid-scan. Watching the camera monitor, experimentally arrive at a good accumulation time by trial and error, and/or by previous experience.

(5) To the dedicated microcomputer, running a control program, key in desired angle scan range, number of incremental angular steps desired, sample size, and desired sampling grid pattern over the LSM face at which absolute reflectivity measurements will be extracted. (Choosing a 20 X 30 sampling grid, for example, will cause the extraction of 600 absolute-reflectivity rocking curves, one for each sampling site on the LSM surface.) Pass control to the microcomputer.

(6) (Under microcomputer control)
Step the Θ-2Θ drive through a user-specified number of discrete, equally-spaced angular settings, spanning the requested Θ-range from $\Theta_{mech\ start}$ to $\Theta_{mech\ end}$.

At each such discrete Θ-2Θ setting,

-- lock the Θ-2Θ drive;

-- clear the frame buffer of any previous contents;

-- accumulate a fresh reflection image of the LSM surface, as per the agreed upon accumulation time, displaying image on the dedicated color monitor as it builds up and completes exposure;

-- Use the current accumulated image in the working frame grabber board and the normalization "direct-look" stored away, together with facility geometric constants, LSM dimensions and sensor readings of current shaft angles and running pickoff source-strength monitor, to compute for each requested LSM sampling site, the local mean grazing incidence angle and local mean absolute reflectivity. Store these numbers away.

-- Unlock the Θ-2Θ drive and step to the next shaft angle setting Θ_{mech};
After completing the accumulation and image-processing at the last angle stop, the recorded data -- one rocking curve for each of the several hundred LSM sampling sites requested -- is processed. This yields up three "maps" of absolute LSM characterization, at whatever was the requested sampling resolution. One map is of absolute peak reflectivity. The second is local Bragg angle. The third is of rocking curve angular full-width at half max. These three summary maps, plus all the individual rocking curves from which they were extracted, and a brief .DOC file of

associated measurement parameters, are all recorded to facility archive, and to diskette for user's copy.

At this point, the dedicated microcomputer releases system control back to facility operator.

(7) After a complete scan is done, the operator can peruse the processed data, and if satisfied with the run, dismount the sample.

A comprehensive algorithm has been implemented in ANSI 'C' code and been run as a detailed multi-frequency simulation of the entire measurement process on a CRAY XMP supercomputer at LLNL. With this code one can freely study the effects of finite source size, source--detector distance, source brightness and spectral distribution , camera QE, camera pixels size and shape. Additionally the number of "full-well" camera x-ray counts allowed each element can be varied from run to run, to permit studies of dynamic range and saturation effects on the corresponding quality of the rocking curves extracted. The flat LSM sample itself can be varied in size, shape, and in the separate spatial distributions of its peak reflectivity, d-spacing, and angular full-width half-max. In looking at x-ray sources, imaging detectors, and the like for their feasibility in a proposed imaging multilayer calibration facility, this design tool lets us speak swiftly and with some authority about what is best and what is worst. Some early work of this design code is shown in Figs. 3, 4, 5.

3. Performance Predictions

What sort of throughput could we expect from an imaging LSM calibration facility? Consider how long it may take to accumulate the image at one of the discrete angular stops. The number of counts recorded by a camera element in time t_{accum} is given by

$$N_{accum} = \text{refl} * \text{transm} * QE * \left(\frac{dn}{d\Omega}\right)_{srce} * \Delta\Omega_{pixel} * t_{accum} \tag{5}$$

Here refl is the reflectivity encountered by the x-rays arriving at the camera element, transm is transmission of source through any intervening UV/VIS light barriers and x-ray filtration. QE is quantum efficiency of the detector element, $\left(\frac{dn}{dW}\right)_{srce}$ is the number of soft x-ray photons/(sec * [ster]) radiated by source per unit solid angle, and $\Delta\Omega_{pixel}$ is the solid angle the camera element subtends about the source.

Hence the required accumulation time is given by

$$\frac{N_{accum}}{\left(\frac{dn}{d\Omega}\right)_{srce} * \text{refl} * \text{transm} * \text{QE} * \Delta\Omega_{pixel}} \tag{6}$$

This technique requires bright soft x-ray sources of wide angular flux patterns and of great spectral purity. Such sources are not commonly available today but do exist. The IONAC proton-beam accelerator at LLNL, for example, provides essentially bremsstrahlung-free characteristic x-radiation from a variety of water-cooled anode targets. For Cu anode (0.932 KeV) , the output is typically around $5.75\text{x}10^4$ x-ray counts in 60 sec through a .0254 cm dia aperture at 100. cm distance from the source. This implies a source output of

$$\left(\frac{dn}{d\Omega}\right)_{srce} = 1.745 \text{ x } 10^{10} \ \frac{[\text{x-ray cts}]}{[\text{ster}]*\text{sec}}.$$

Consider a fluor/coherent-fiber array driving a visible-light CCD chip as a candidate imaging technology. A single 2mm by 2mm fluor-fiber detector camera pixel at 100. cm from this source subtends a solid angle of $\Delta\Omega_{pixel} = 4\text{x}10^{-6}$ [ster] about a source point. Assume an overall QE of $5\text{x}10^{-4}$ for this camera element. This is 1% fluor x-ray to VIS/UV energy conversion efficiency, times 10% geometric light collection efficiency, times 50% detection efficiency of the VIS CCD chip. Taking transm = 0.8, refl = $1\text{x}10^{-2}$ typical over the LSM, then the accumulation time t_{accum} required for an $N_{accum} = 50$ x-ray counts is, by Eq. 6 above, t_{accum} = 179.08 sec. As one might imagine a typical LSM imaging job to involve a few-degrees scan broken up into 100 or so accumulations, the corresponding total x-radiation time required is 4.97 hours. Going to direct x-ray detection with one of the new back-side-illuminated, thinned x-ray CCD chips would boost the overall imaging-element QE by three orders of magnitude. However, as each such camera element is typically only 20 microns square, the required accumulation time works out to be 5 times longer than if one sticks with the 2mm by 2mm fluor/fiberoptic elements. Shortening the source to camera x-ray path length from 1 meter would shorten this time, as would having a brighter x-ray source or greater detector efficiency.

By comparison, the time required to *process* one accumulated image before we can start acquiring the next, is much less a constraint on system throughput. Timing runs of the imaging code developed for this work have been carried out on an Everex Step 386/20MHz 32-bit AT-class microcomputer equipped with an Intel 80387 numeric coprocessor. (This is a typical microcomputer as might be dedicated to work at a multilayer imaging facility.)

The time required for all of 16 X 12 = 192 LSM sampling sites to "study" a 320 X 480 pixels frame-grabber board and process it for local grazing incidence angle and associated local mean absolute reflectivity, would about 1.50 sec. This is for code generated with a Microsoft C5.1 optimizing 'C' compiler, running under MS-DOS version 3.3 operating system.

Clearly, for currently-available soft x-ray sources, the bottleneck in this imaging technique will tend to be source brightness, not image-processing throughput.

4. Summary and Suggestions for Future Work

The potential for absolute calibration of flat LSMs at high spatial resolution via real-time soft x-ray imaging has been addressed in a design study. An experimental procedure combining the traditional fixtures of the soft x-ray laboratory with recent commercially-available image processing technologies, has been outlined.

Given currently available soft x-ray source brightnesses, calibrations of excellent angular resolution (i.e., 4 degrees in 100 - 200 discrete angle stops) and at millimeter spatial resolution over the face of the flat LSM under test, can be expected to take several hours. This means a facility throughput of only one or two wafers a day (but at extremely high quality).

Enhancements in throughput will hinge on developments of higher-brightness, small spot-size soft x-ray sources, and in development and utilization of high quantum-efficiency soft x-ray imaging devices. Good candidates for camera technologies should have quantum efficiencies well in excess of one percent, yet be manufacturable in large sizes (several cm on a side).

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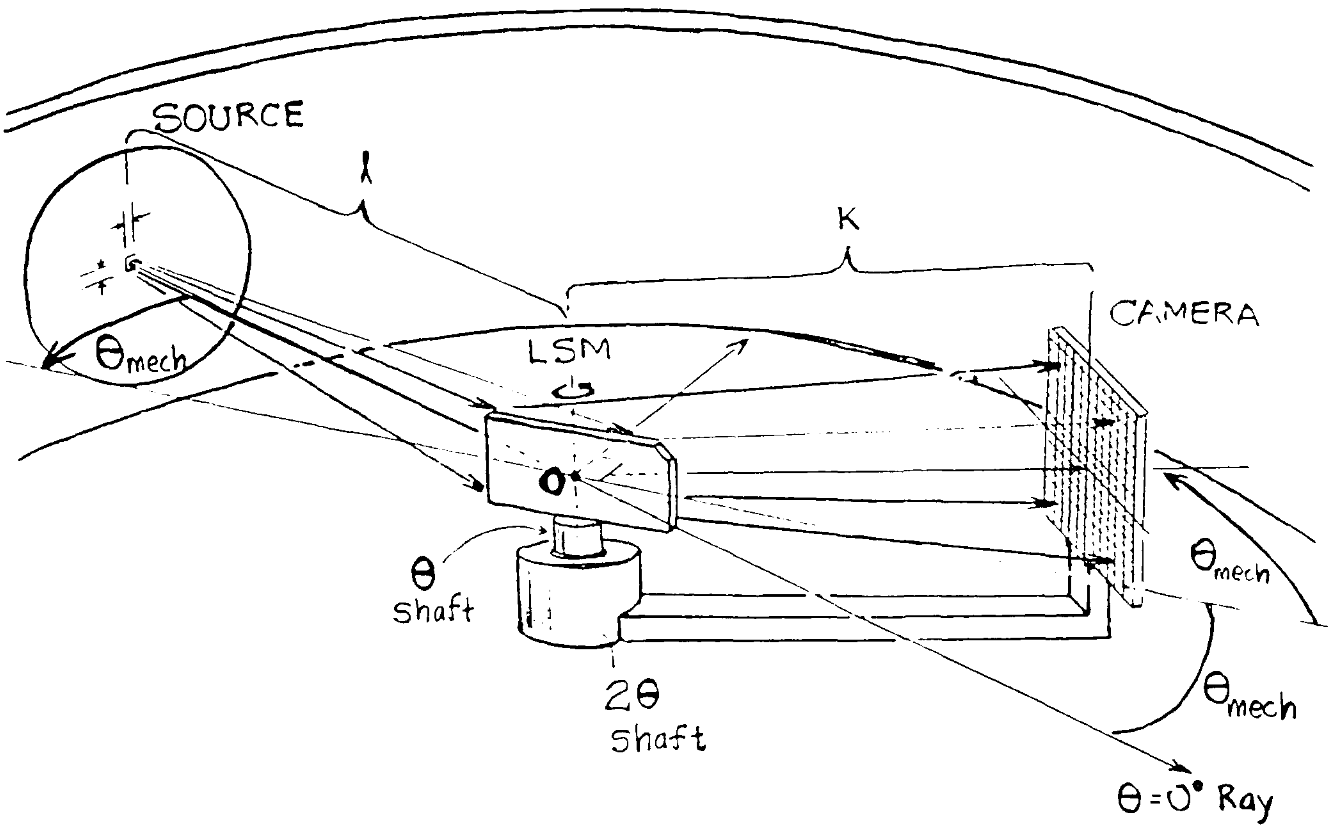
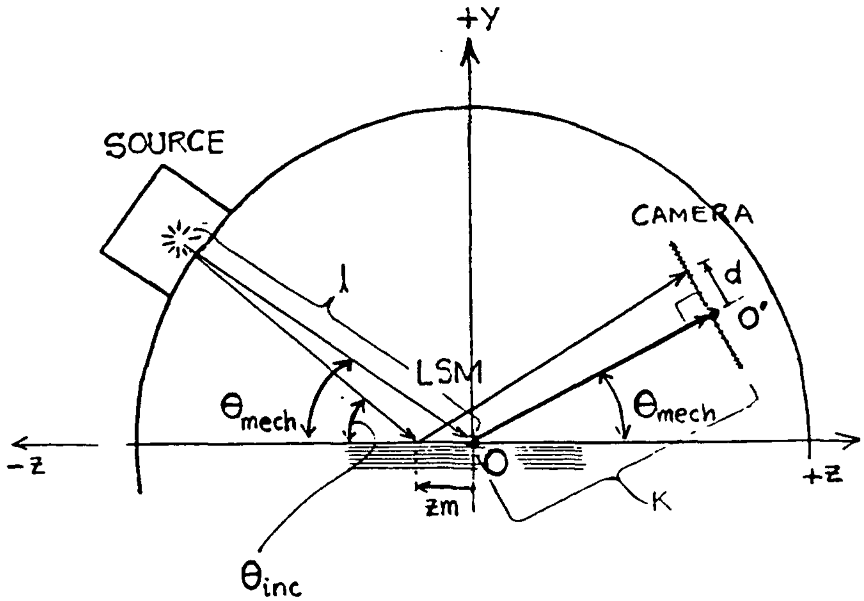


Fig 1. Overall chamber layout for real-time soft x-ray imaging of flat LSMs. The three main elements are the Source, LSM under test, and Camera (an array of position-sensitive soft x-ray detectors each of which has independent photon-counting capability). The origin **O** of spatial coordinates is the center of the LSM. Distance from center of source to center of LSM is denoted by l. Distance from center of LSM to center of camera is denoted by k. Plane of the LSM is plane y=0.



$$d = d(zm, l, k, \Theta_{mech}),$$

$$= \frac{k * \cos\Theta_{mech} * \tan\Theta_{inc} - k * \sin\Theta_{mech} - zm * \tan\Theta_{inc}}{\sin\Theta_{mech} * \tan\Theta_{inc} + \sin\Theta_{mech}},$$

where

$$\tan\Theta_{inc} = \frac{l * \sin\Theta_{mech}}{zm + l * \cos\Theta_{mech}}$$

Fig 2a. For any given source point and for any given point on the LSM plane, the there is a corresponding point on the camera plane where a ray connecting source point to LSM point is specularly reflected. The arrival point on the camera of this specularly reflected ray will generally change as the mechanical shaft angle changes. The relationship is expressed in the equation in the figure. For a given LSM sampling site's midpoint projection onto the camera plane, arrival-coordinate d can can easily "walk" by several millimeters during the course of a 4 degree scan in θ_{mech}. This and other distortions, as well as the tedium of analyzing 100 or so frame-buffers worth of Bragg-diffracted x-ray count pictures, mitigate against the "eyeball" analysis of raw images of Bragg-diffracted x-ray counts.

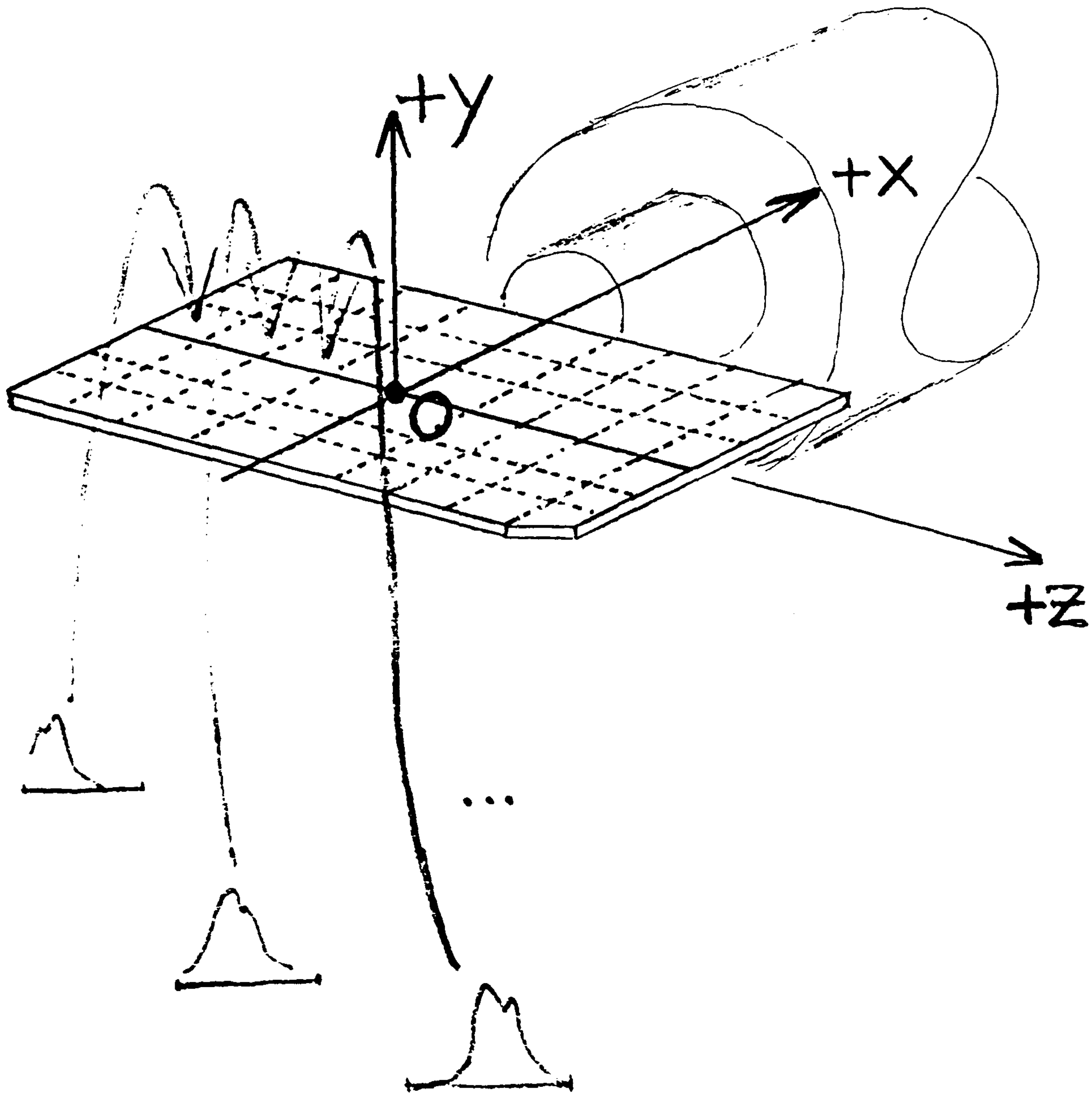
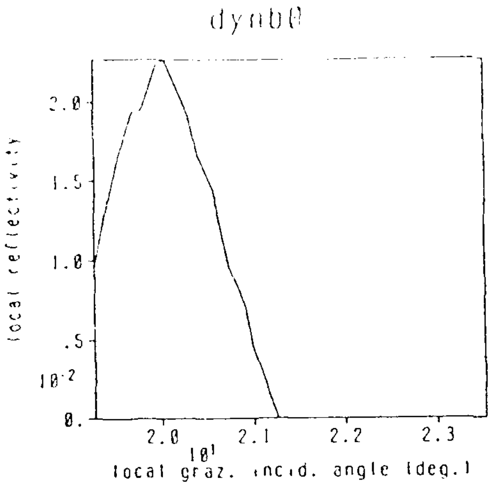
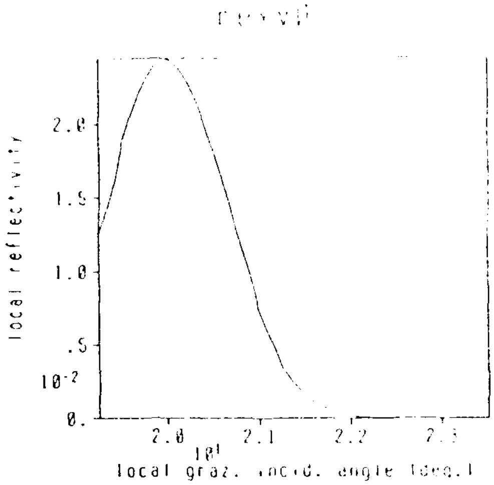


Fig 2b. The center of the LSM is the spatial origin of the 3D coordinates of the problem. Plane y=0 is the LSM plane. +X-axis points down through the axis of chamber Θ-2Θ drive . Imaginary dashed rectangles on LSM represent user-specified sampling grid. For finite source-to-LSM distances, at any one mechanical shaft angle θ_{mech} , different sampling sites over the LSM will have different (mean) local grazing incidence angles. One sample site might be at its Bragg peak, while another elsewhere on the LSM is far out on the tail of its rocking curve.


dynb0
local reflectivity
2.0
1.5
1.0
.5
10^{-2}
0.
2.0
2.1
2.2
2.3
10^{1}
local graz. incid. angle (deg.)


local reflectivity
2.0
1.5
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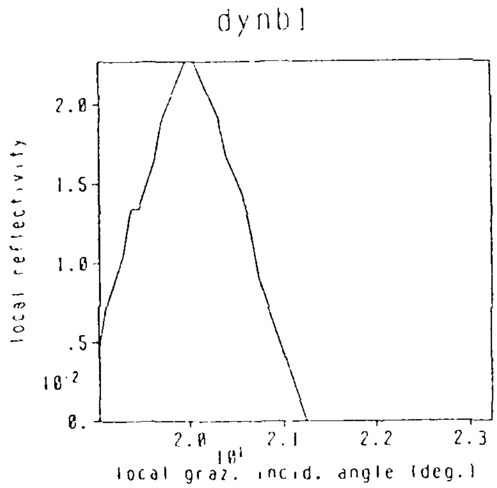
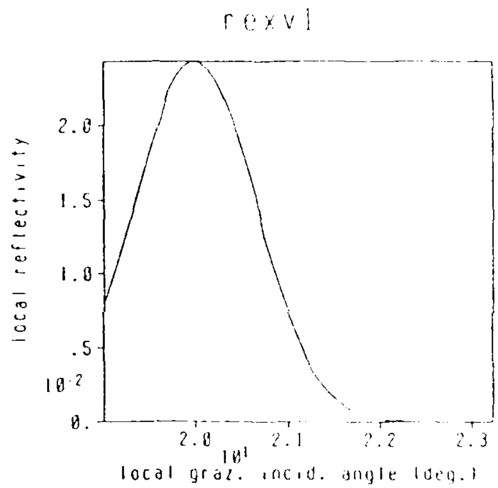
2.1
2.2
10^{1}


dynb1
local reflectivity
2.0
1.5
1.0
.5
10^{-2}
0.
2.0
2.1
2.2
2.3
10^{1}
local graz. incid. angle (deg.)


rexv1
local reflectivity
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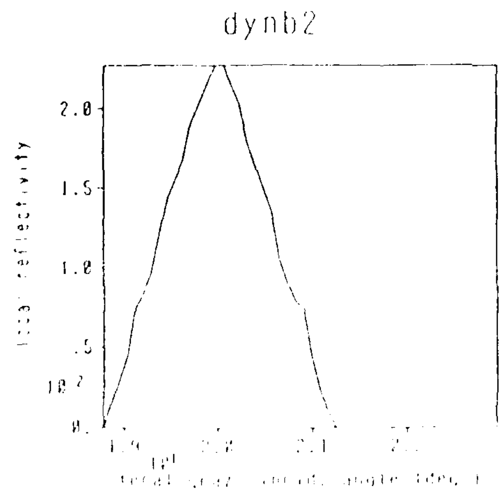
1.0
.5
10^{-2}
0.
2.0
2.1
2.2
2.3
10^{1}
local graz. incid. angle (deg.)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1.5
1.0
.5
10^{-2}
0.
10^{1}

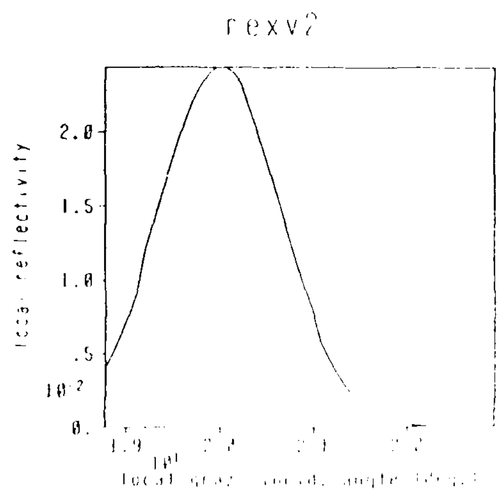

rexv2
2.0
1.5
1.0
.5
10^{-2}
0.
1.9
10^{1}

Fig 3. Part of a dynamic range study with the LSM imaging design code tool. Left and right columns each bear three rocking curves taken from successive contiguous sampling-sites on an LSM mocked up to be spatially-uniform in its rocking curve attributes. Input LSM configuration is spatially uniform peak reflectivity of 2.5×10^{-2} , angular half-width half-max of 1.5 degrees, Bragg angle to peak at 20.00 degreees with 0.703 KeV x-radiation. Chamber geometry, camera, and source are as follows:

$L = 35.0$ cm, $k = 15.0$ cm
height of source = 0.1 cm, width of source = 0.1 cm
height of lsm = 2.54 cm, length of lsm = 5.08 cm
height of camera = 5.08 cm, width of camera = 4.50 cm

camera : 40 pixels vert by 60 pixels horiz; $QE = 1 \times 10^{-1}$
camera amplitude res. = 15 bits
($2^{15} - 1 = 32{,}767$ discrete x-ray counts full-well before pixel roll-over)

x-ray source spectrum:

$E_{center} = 0.703$ KeV, $\Delta E_{FWHM} = 0.005$ KeV, peak $= 5 \times 10^{8}$ $\frac{\text{photons}}{\text{sec} * [\text{ster}]}$

Scan: $\Theta_{mech\_start} = 18.0$ deg., $\Theta_{mech\_end} = 22.0$ deg.

Sample Sites, Center Points:
dynb0, rexv0: x-coord = 0.1058 cm, z = -2.328 cm
dynb1, rexv1: x-coord = 0.1058 cm, z = -1.905 cm
dynb2, rexv2: x-coord = 0.1058 cm, z = -1.482 cm

$t_{accum} = 1.032$ sec for dynb series, 103.2 sec for rexv series

The digitized nature of the signal amplitudes recorded by the discrete camera elements is fully taken into account by the CRAY XMP simulation code. LSM sampling grid is 12 X 12 sites. Analysis showed that the extracted rocking curves reproduced 97.8% of the input peak reflectivity, and reproduced the Bragg angle to within +/- 0.2 % of its input value.

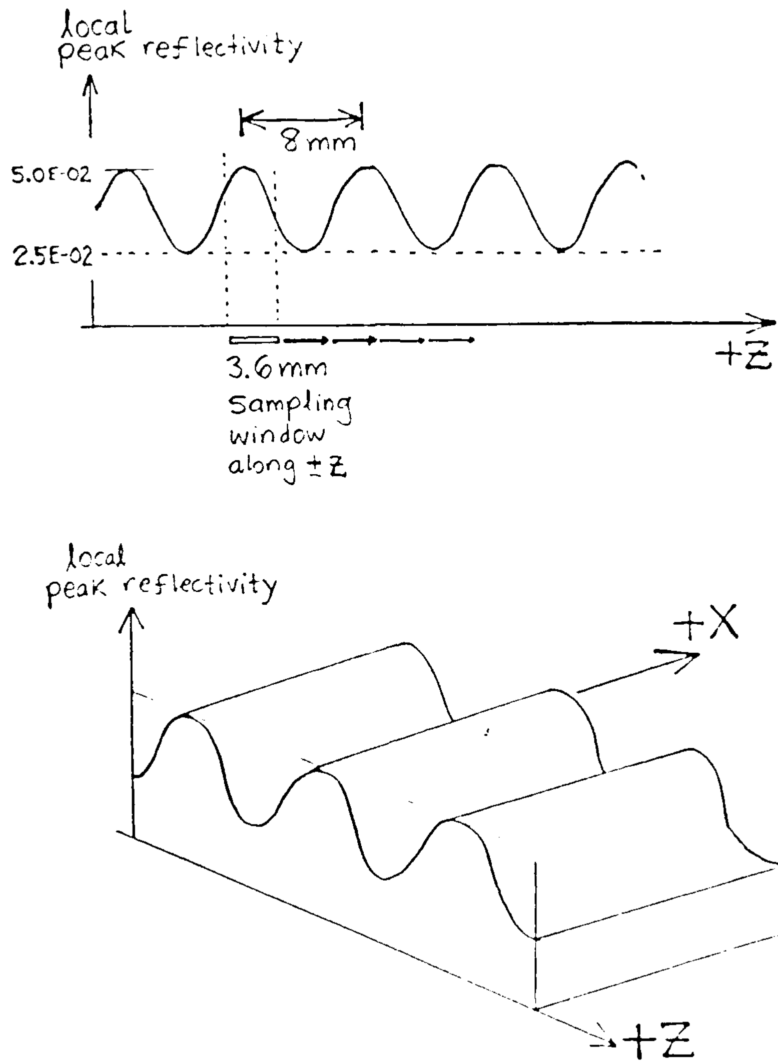
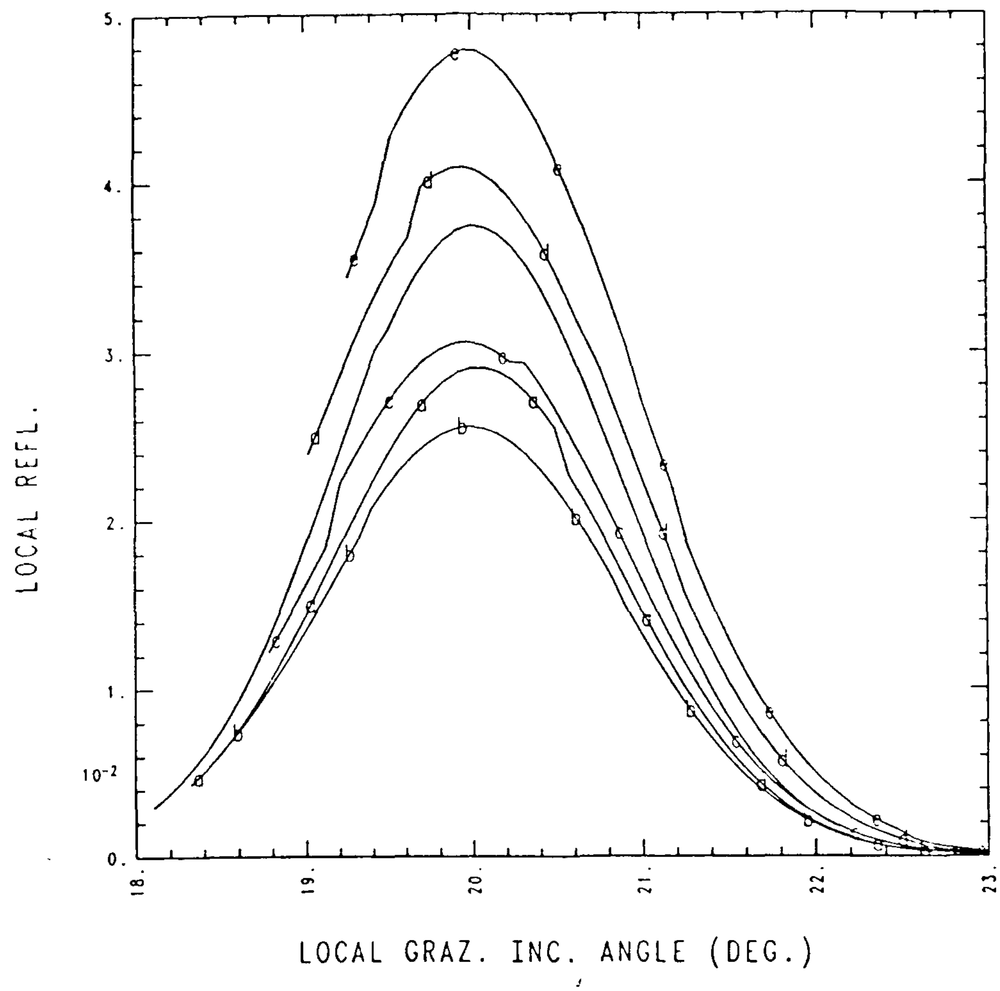


Fig 4. Test input for LSM imaging algorithm now features a spatially-periodic local peak reflectivity, varying from 2.5×10^{-2} to 5.0×10^{-2}. Other LSM parameters are same as in Fig 3.



Trace	Sample Site Coordinates
e:	x-coord = 0.1058 cm, z = -2.328 cm
d:	x-coord = 0.1058 cm, z = -1.905 cm
c:	x-coord = 0.1058 cm, z = -1.482 cm
b:	x-coord = 0.1058 cm, z = -1.058 cm
a:	x-coord = 0.1058 cm, z = -0.635 cm
plain:	x-coord = 0.1058 cm, z = -0.212 cm

Fig 5. Computed response to input LSM of Fig 4. Chamber geometry, sampling site grid, source spectrum same as for Fig 3. Shown are the extracted absolute local rocking curves from a succession of contiguous LSM sampling sites marching down the z-axis of the LSM. Note how, although the mechanical shaft angle scan begins at 18.0 deg., the corresponding local grazing incidence angles of the various sampling sites are staggered with their position on the LSM and in accordance with the angular spread the slanted LSM subtends about the x-ray source. Calculations like this can give insight into how spatial resolution of the imaging technique depends on x-ray source spectral bandwidth, camera element size, sampling grid over LSM, source size and so on. Key point to note is that the extracted curves of local mean reflectivity faithfully track the characteristics assumed of the input LSM.

Mr. Albert Green, Stanford University (left) and Mr. Gerald Davis, LLNL (right)

A Window on High Energy Physics in the Next Century: The Superconducting Super Collider

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Department of Physics
Ann Arbor, Michigan 48105

Introduction

I am pleased to have this opportunity to address you today on the subject of the Superconducting Super Collider -- the largest basic research project ever undertaken. This project can be described by a high energy physicist only in superlatives, for it is the largest, most costly, and most exciting scientific project of its type; it holds the promise of greatly advancing our understanding of the basic laws of nature.

In my presentation today I want to review in the most general of terms what the SSC project is, how it evolved, what the physics goals are, how it operates, how long will it take to build, what it will be like to work there, and the politics and economics of its funding.

First, I should wade right in and state what it is we are talking about. The SSC is a large, 53 mile circumference, particle accelerator that will accelerate counter-rotating beams of protons to an energy of 20 trillion electron volts each and cause these beams to collide so that the products of the interactions can be studied in an attempt to learn more about the basic laws of physics. The laboratory will be located approximately 30 miles south of Dallas, Texas, will employ approximately 2500 scientists and other staff when it is completed by the end of this century; the projected total project cost is of the order of $7 billion. That's the short explanation of the project. Now, in keeping with the practice in academe, let's see if we can say the same thing by increasing the number of words by a couple orders of magnitude.

What's in a Name

To begin let us look at the name of the SSC-- the Superconducting Super Collider. As is often the case, one can achieve maximum understanding by working backwards. The primary goal of high energy physics -- the branch of physics most directly related to the SSC -- is to find the basic constituents of matter and to understand the forces between these constituents. One of the most direct ways of acquiring information of this type is through colliding very basic particles such as protons and observing the behavior of the resulting products. In the case of the SSC, beams of counter-rotating protons are caused to collide at speeds very near the speed of light. This is the origin of the term "Collider".

Now what about the term "Super"? This is just the physicist's awkward attempt to state that the energy of the SSC will be far greater than that of any other accelerator built until now. For example, the SSC will produce energies of 40 trillion electron volts, an amount that is twenty times that of the present largest accelerator (Fermilab).

Continuing to work backwards in the title, we encounter the term "Superconducting"; what does this mean? Superconductivity is a phenomenon in the realm of solid state physics where certain materials can carry currents while presenting essentially no opposition (resistance) to the flow of that current. Materials with this property are quite special, and must be maintained at very low temperatures (near -450 degrees Fahrenheit) for the "superconducting" effect to be observed. The SSC needs to take advantage of superconducting materials because the very large currents required by the thousands of large magnets which keep the circulating protons moving in a circle can only be provided practically if the power consumption can be kept at a very low rate. That's where superconductivity enters the project. The SSC will need 60 million feet of niobium-titanium-copper superconducting cable in the fabrication of approximately 10,000 magnets (most of which are some 50 feet long).

The tunnel has a diameter of approximately 10 feet -- just large enough to hold the magnets (through which the beam passes), and to have room for accessing the magnets at any spot around the 53 mile circle. The tunnel is never closer than 30 feet to the surface. At fixed positions around the tunnel are large buildings which will contain the sophisticated detectors used to detect the products of the collisions between the two beams of protons.

How Did It Evolve?

The SSC is one more step in a long series of particle accelerators all designed to push back the frontiers of knowledge as far as possible given the technology of the day. The first man-made accelerator capable of accelerating protons to a high enough energy to break open the nucleus was the cyclotron, in the early 1900's. That machine produced protons with energies of several million electron volts. From then onwards, we have been increasing the energy attainable by an order of magnitude almost every decade. How can this be? It is the direct result of hard work by clever individuals who either think of better ways to use existing technology or recognize how to use new technology to produce more intense and higher energy machines. So, in many ways, the emergence of the SSC should not be any great surprise to us; this time it is a combination of the ability to build a huge device while adhering to small tolerances, to build large magnets with very low power dissipation as a result of advances in superconductivity, and to capture advances in computation and electronic for the necessary control circuitry, the design of detectors and the analysis of the resulting final data. Nevertheless, the SSC is daunting and clearly represents some kind of "outer limit" to machines of its type. For example, it is doubtful in the present world climate that we could find either the real estate or the money to build a machine that is twenty times larger. Indeed, we would soon be faced with a "Globe Circler" if this trend were to continue. The next advance in machines will likely occur in some very different way -- a way that will permit much higher energies to be attained per acre of laboratory space. This may be possible in future decades as further advances are made in superconductivity research.

The SSC is the product of years of planning and design by the high energy physics community, as it focused on the question of what is the next appropriate step to close in on the remaining unanswered questions. At the federal level, the project is coordinated through the Department of Energy (DOE), and this agency has entered a management agreement with the Universities Research Association to oversee the construction and operation of the laboratory.

Physics Goals

It is well-known by many of you that to examine features of matter in finer and finer detail, larger and larger instruments are required. A small cyclotron in the basement of a physics building could be used to examine objects of nuclear dimensions. To study protons or

neutrons, the constituents of the nucleus -- having dimensions of order 10 times smaller than the nucleus -- one needs instruments that are comparable to the size of a large university. To look at what might be inside a proton (for example, the quark, at dimensions yet one thousands times smaller than the proton), one needs laboratories of the size of Fermilab, capable of holding several large universities. The SSC, which may indeed see inside the quark, must be capable of holding several Fermilab. Indeed, one of the possibilities considered for the SSC was to have the present Fermilab serve as the injector for the SSC -- the SSC then becoming the device that took a 2 TeV proton from the Fermilab constellation of machines and boosting its energy to 20 TeV.

The SSC is so large because its goal is to examine distances down to a millionth of a millionth of a millionth of a centimeter. At these distances we can begin to answer the question as to whether the quark itself has structure. On this topic of structure, let us back up to something more familiar than quarks. Consider a biological cell, which we know, among other things, to be made up of strands of DNA material that has the entire genetic coding for the specific individual of the species. That DNA is made up of complex molecules, each consisting of an array of atoms of well-know elements. Each one of these atoms has a nucleus made up of a precisely known number of protons and neutrons with a cloud of circulating electrons. Thus, when one asks what is inside the proton or neutron, he or she is asking about the fundamental make-up of all matter. That is one of the reasons high energy physics is often referred to as "fundamental particle physics". This area of study ties together almost all other fields of physics -- and almost all fields of science.

We have come a great distance this century in understanding the relationship between the various basic components of matter. From the molecule to atom to nucleus to nucleon to quark. Every time we look for something inside of something else -- we find it. Will this ever end? If it does end, why does it? If it doesn't end, why doesn't it? Such questions touch not only upon science, but on philosophy and religion as well. This is just some of the excitement associated with the SSC.

There is another reason for the great interest of physicists in the SSC. We are hoping to gain some insight into the origin of the mass scale. To elaborate, physicists can recite the mass of the electron, of the proton, the lambda, and so on. But we do not know why these particles have the masses they have. A complete theory should be able to predict these masses. One very popular notion in our field is that the mass scale could be determined by a hitherto undiscovered particle called the Higgs boson. Its decay properties are fairly well

postulated, and the rush to find it will clearly be one of the highlights of high energy physics research in the next decade.

An additional quest of high energy physicists is the unification of the basic forces of nature. There now seem to be three distinct types of forces -- the electroweak, the strong and the gravitational forces. Every interaction we observe seems explicable in terms of one or more of these. But the puzzle is why there are three different forces; it would be more palatable if there were just a single descriptive forces. As we learn more about the nature of the forces between fundamental constituents, we hope to move closer to realizing the dream of a unification of these forces.

Finally, in this general vein of some easily related physics reasons for interest in the SSC, I want to mention the coupling between SSC research and the work of astrophysicists. First, let's recall that the most persuasive model of the creation of the universe is that of the Big Bang model, in which all mass in the universe was concentrated at one point some 15 billion years ago, and that the universe as we know it today evolved from that point via a "Big Bang" explosion. Astrophysicists are very interested in the conditions of high energy density that existed immediately following the Big Bang -- since models of how the galaxies developed in the ensuing millennia depend on these parameters. The energy density achieved when two protons collide at the SSC will be comparable to the densities that are presumed to have existed just a very small fraction of a second following the Big Bang. Thus, findings at the SSC will be of direct interest to the astrophysicists.

In summary, with the SSC we want, among other things, to learn more about the composite structure of matter, learn more about the origin of mass, more about the relation between the fundamental forces, and more about the evolution of the Universe. When it comes to setting goals, we physicists do not skimp.

Schedule for Completion

In my early days as a physicist, new laboratories (e.g., Fermilab) could be completed in approximately three years after Congressional authorization. The SSC will require approximately eight years. The process is moving along quite well; already several hundred individuals have been assembled near DeSoto, Texas to form the infrastructure of the new laboratory. Nevertheless, it will be toward the end of this century before practicing physicists can hope to get their first useful data.

Eight or so years is a long time -- and this lengthy period creates several interesting sociological problems. First of all, many present faculty in their late fifties look upon the SSC with a special concern. Should they devote years of their lives working on a facility that they may never have a chance to use for actual experimentation? Very young faculty these days have a different problem. Should they devote a large fraction of their efforts to a machine that will not produce data until long past the time that they will have to be evaluated for tenure and promotion? What will they say when their senior colleagues ask them three years from now "where s the physics you have done? ... we have to decide whether or not to keep you on the faculty and the only way we can decide is to examine how you have advanced the field of physics by acquiring data, analyzing it, and publishing the results".

The situation for graduate students is not much different, unless our universities become more enlightened and permit more students to receive their degrees based on novel hardware development. It is very important that a steady flow of talented graduate students be sustained for it is they who will ultimately exploit the SSC to its full potential.

There is much to be done on the SSC, and it will require the best minds the field has to offer. Ways have to be found to bring individuals on board, and to ameliorate some of the side effects mentioned above.

Questions such as the design of the magnets, their construction, beam design, the numerous injector stages, the design and construction of several hundred million dollar detectors, and so on are all activities that must be carried out at a feverish pace from now until the end of this century.

What Will It Be Like to Work at the SSC?

In addition to taxing technology, the SSC will test the ability of large numbers of talented individuals to work together toward a shared goal. A typical experiment at the SSC may involve 700-800 physicists and students. Can that many scientists work together? How can the individual contributions of young people be recognized, thereby giving them the type of positive feedback they need to persevere? Who could possibly manage such a large group of people who are predisposed to being individualistic? How are decisions reached when there are numerous options, each supported by different strong factions within the collaboration?

These are really tough questions, but we have reason to believe that that they are tractable. Present day experiments at Fermilab and CERN, for example, are not small. We have examples of several successful experiments being conducted by groups of several hundred physicists. In spite of the large overall size of the groups, most of the work gets done in small subgroups of 5 - 15 people. Moreover, the very brightest people still rise to the top.

A couple of years ago, a DOE High Energy Physics Panel committee of which I was a member looked into some of the questions and concluded that group size was not likely to limit our ability to exploit the SSC if care was taken in establishing the management plans.

A typical early SSC experiment may take five years to design, construct, and test; another 3 years of data-taking may be required, followed by a year or two of analysis before the most important findings are published. Clearly, a few key people will have to be so devoted to a particular experiment that they are willing to make it a cornerstone of their professional life. Indeed, they may only expect to be able to play a major role in only 2-3 such endeavors in their entire professional life.

Graduate students, after finishing their course work back at their university, can expect to spend some 4 years at the Laboratory working on their experiment. Depending on the timing of their arrival relative to the execution of the experiment, some will naturally emerge with more experience in hardware projects than in software/analysis projects. Part of this disparity can be corrected later at the postdoctoral level, if care is taken.

The Laboratory recognizes that it has a special obligation to help interest more students in careers in science -- any area of science. Our country is presently faced with the puzzling situation of needing more and more of its citizens to be scientifically literate at precisely the time when interest in science is declining. Moreover, as is generally recognized, the nation's need for future scientists and engineers can not be met unless more females and minorities are attracted into these fields. The Laboratory will be instituting special programs to address these issues at both the pre-college and college levels.

The Politics and Economics of the SSC

Current estimates for the cost of the SSC approach $7 billion dollars. This is not an insignificant amount in any accounting scheme. Indeed, in the science arena, the sum is huge, and many have appropriately been concerned about possible distortions the SSC will

introduce in the overall support of science. To provide an additional perspective, however, physicists often point out that the SSC is equivalent in cost to a few of stealth bombers. In any case, it is clear that the country must view the funding of the SSC as a priority that spans the entire federal budget, for the country will not benefit at all if the SSC is built by draining resources from other fields of science. The point must repeatedly be made that our country is spending too little on basic research -- particularly given the fact that our future is so dependent on advances in a broad spectrum of science and engineering fields in the decades ahead.

Since I have made the invidious comparison above of the relative costs of the SSC and a stealth bomber, I need to also acknowledge another type of comparison that is made. This was most forcefully and eloquently made to me in a meeting I held with Congressman

William Gray at the time he was Chairman of the House Budget Committee. I had visited him in his Washington office to seek his support for the SSC. He noted that, in an environment where taxes were not to be raised and where military spending was to be protected, my request of him for funding support of the SSC was tantamount to a request to cut various social programs, including many that he was deeply committed to. On the one hand, the SSC can easily be viewed as a project that is "peanuts" when compared to advanced military hardware projects, but on the other hand, it can be viewed as a giant that robs the poor and the homeless of support that their government should be giving them. We all are, of course, torn by these two interpretations. The justification, I believe, for proceeding despite the possible impact on social programs is that a nation's investment in advanced basic research almost always reaps returns that far outweigh the short term pressures. Advances based on spin-offs from SSC research may help resolve the very problems which are now seen as competing with the SSC for federal support.

The following historical advances are frequently cited by DOE. Magnetic Resonance Imaging and CAT Scans, which utilize superconducting magnets, which enable doctors to see inside the body and determine the locale and size of tumors, have become practical because of advances in superconducting cables spurred by physics research needs. Fermilab is now building a special accelerator for the Loma Linda University Medical Center for the treatment of cancer. Accelerators are being used to make smaller computer chips with increased memories. Accelerators are being used to remove noxious chemicals

from smokestack emissions. Moreover, American industries utilize high power radio frequency systems, ultra-high vacuum systems, precision beam optics, and data control systems, all of which are spin-offs of particle physics.

The SSC will require an enormous number of components to be supplied by industry. In many cases, the state of technology will be pushed to and slightly beyond existing limits -- and this is just what we need. I have already mentioned the need for 60 million feet of superconducting cable for the 10,000 superconducting magnets. Also, according to DOE there is also the need for:

- 10 million cubic feet of concrete for the tunnel 10
- 110 miles of stainless steel bore tubes
- 100,000 tons of iron and 5,000 tons of lead for the experimental detectors
- 44,000 tons of iron for the magnet yokes
- 11,250 tons of stainless steel for the magnets
- advanced electronics to instrument the detectors for up to 1 million channels
- the world's largest liquid helium refrigerator, with an initial inventory of 2.4 million liters
- the equivalent of several of today's super-minicomputers to acquire and monitor data for each experiment, and the equivalent of 100 of today's mainframe computers for off-line analysis.

There can be no doubt that the SSC will have an impact on industry and, indeed, the process of industrial involvement in the magnet manufacturing task is well along. Studies conducted at the European laboratory CERN have shown that every Swiss franc spent by CERN on high technology produced approximately 3.5 francs of new business for the firm involved [CERN Courier, Jan/Feb 1985]. As companies structure themselves to meet the challenges of orders from high energy laboratories, they greatly enhance their capabilities to provide better services and products to other consumers. So, some fraction of the SSC

costs must certainly be viewed as leveraging the entire national economy. The need for a more vigorous push in the high technology sector is evident from the fact that in 1986, for the first time, our balance of trade in high technology products went negative. That is, we are having to buy more high technology goods from foreign countries than we sell -- a turnabout for our country that few could have imagined would happen.

During the period from 1984 to 1988 approximately $115 million was spent on planning and R/D for the SSC. The appropriation for FY89 was $100 million. For FY90 the President's Budget contains a total request of $250 million, $90 million for R/D and $160 million for construction. There is considerable debate these days as to what the total project cost will be, and the conditions under which federal funds will be released for the project. Stay tuned.

Conclusion

We are living in a marvelous period of human history. We are poised to explore unknown regions of the Universe with new facilities such as the Space Telescope, and to explore inner space with tools such as the Superconducting Super Collider and the Human Genome project. Moreover, these large scale endeavors are just part of an overall mosaic of progress in science involving thousands of individual ingenious scientists and students working on frontier problems. An optimist can find many reasons for looking to the future; among those reasons is certainly the enhanced prospect in the decade ahead of learning much more about our Universe, its laws, its origin, and ways for using this information to make a better life for all.

The Superconducting Super Collider

- A proton accelerator-collider with an energy of 20 TeV per beam; 40 TeV in the collision center-of-mass.

- Very high interaction rate, or "luminosity"; about 10^8 interactions per second.

- Physically large; a 53 mile circumference oval in an underground tunnel 10 feet in diameter.

- But generically the same as existing cascaded accelerators and collider complexes at Fermilab, CERN, and Serpukhov.

- Made possible by the proven technology of superconducting accelerator magnets pioneered at the Fermilab Tevatron.

SSC LABORATORY GOALS

Create a Premier International High Energy Physics Laboratory by the Year 2000

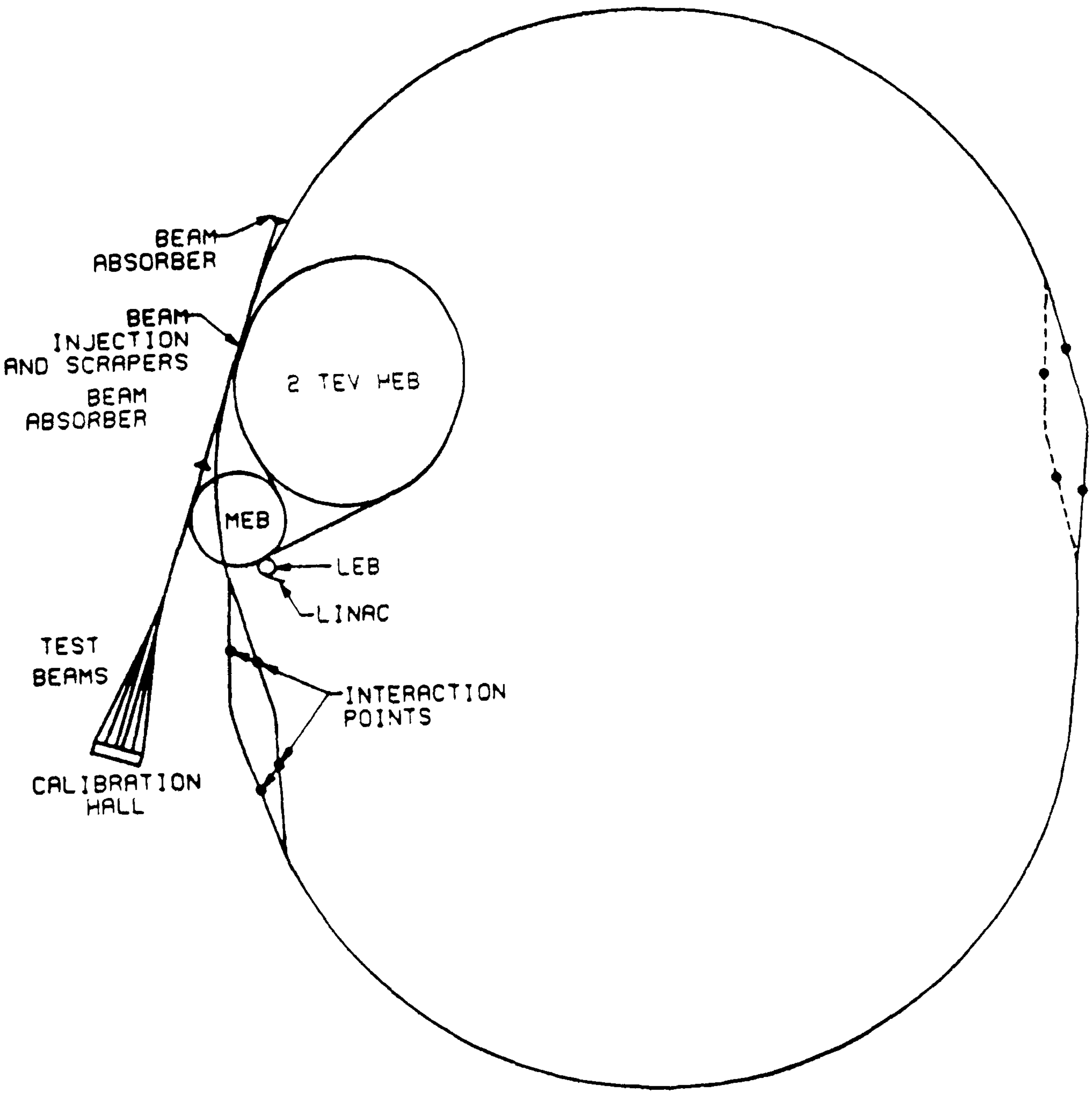
Create a Major Resource for Science Education

Create Laboratory Whose Activities are Carried out in Safe, Responsible, and Environmentally Sound Manner that Respects Human Rights and Individual Dignity

The SuperCollider

Products

- ☐ Knowledge
- ☐ Improvements in Education
- ☐ A Cadre of Outstanding Scientists and Engineers
- ☐ Enhanced Industrial Capability
- ☐ Methods and Tools for Other Applications ("Spinoffs")
- ☐ Local Economic Impacts



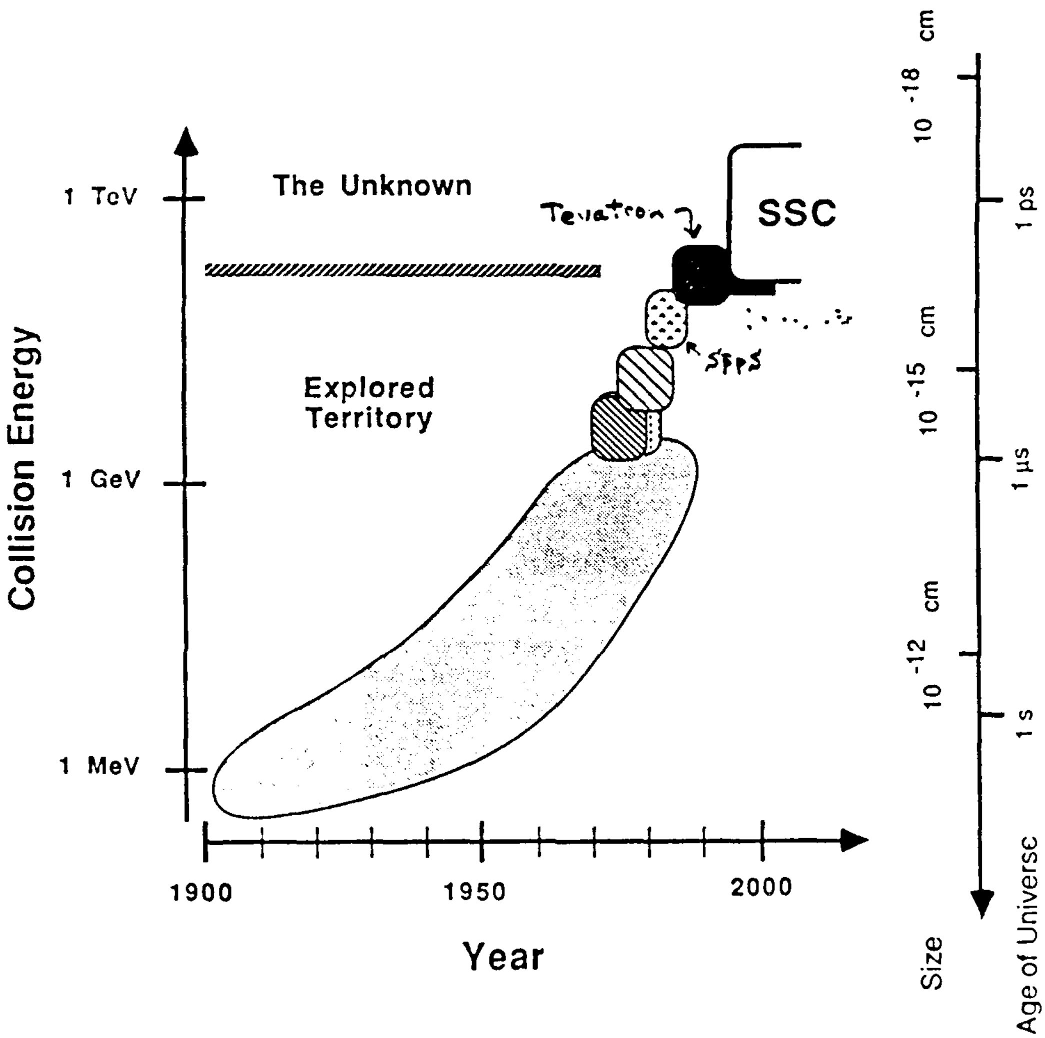
SSC ACCELERATOR SCHEMATIC

Pre-Decisional Draft

Table 4.1-1
SSC Parameter Summary

type of machine	proton-proton collider
beam energy, max	20 TeV
circumference (revolution frequency)	82.944 km (f_0 = 3614 Hz)
straight-section configuration, initial	West cluster: 2U + 2XL (β^* = 0.5 m) East cluster: 2U + 2XM (β^* = 10 m)
luminosity at β^* = 0.5 m/10 m	10^{33}/cm^{2}s/5.6 × 10^{31}/cm^{2}s
bunch separation, no. bunches per ring	4.8 m (min), 1.71 × 10^4 (max)
avg. no. reactions/bunch crossing at 10^{33}/cm^{2}s	1.4 (90 mb cross section)
no. protons	7.3×10^9 per bunch, 1.27×10^{14} per ring
beam current	2.0 A (pk), 73 mA (avg)
beam energy per ring	405 MJ
normalized transverse emittance	1.0×10^{-6} rad-m
luminosity lifetime	~1 day
synch. rad. power	9.1 kW per ring
synch. rad. energy damping time	12.5 h
beam-beam tune shift, linear/long-range, XL	0.84×10^{-3}max/2.1×10^{-3} per IR
rms energy spread, inj/20 TeV	1.75/0.5×10^{-4}
long emittance, inj/20 TeV (rms area/π)	0.035/0.233 eV-s
arc lattice/total no. long-arc cells	FODO, 60°, 192-m cells/332
betatron tune, x,y	78.27, 78.28
momentum compaction factor	0.000223
natural chromaticity	−204
nominal IP space betw. magn. quad ends	±20 m (± 101 m)
beta max, min in arc	332, 111 m
horiz dispersion, max, min in arc	3.92, 2.36 m
crossing angle	75 μrad (typ), 150 μrad (max)
distance between adjacent IPs	2.40 km
angle between adjacent IPs	106 mrad
superconducting magnet type	collared, cold iron, 1-in-1
magnet configuration	over/under, 0.7 m separation
magnetic field, dipole	6.6 T (max)
magnetic radius of curvature	10.1 km
magnetic gradient, arc quad	212 T/m
dipole length (magnetic/slot)	16.54/17.34 m
arc quad length (magnetic/slot)	3.32/4.32 m
no. regular SC dipoles/quads (both rings)	7680 horiz. dipoles/1776 quads
excitation current (dipole and cell quad)	6504 A (nominal)
vacuum chamber ID, normal	3.226 cm
rf: frequency/wavelength/harmonic	374.74 MHz/0.80 m/103,680
acceleration period	1000 s
energy gain per turn per proton	5.26 MeV
peak rf voltage/total rf power per ring	20 MV, 2 MW
rf system slot length (per ring)	25 m
rms bunch length	6.0–7.3 cm
synchrotron tune (inj/20 TeV)	8.2/1.9×10^{-3}
Injector system	0.6 GeV linac, 8 GeV/c LEB, 100 GeV MEB, 1 TeV HEB

Reproduced from the Superconducting Super Collider Conceptual Design Report (SSC Central Design Group, Berkeley, CA), March 1986, p. 95.



Collision Energy
1 TeV
1 GeV
1 MeV
The Unknown
Explored Territory
Tevatron
SSC
SppS
1900
1950
2000
Year
10 -18 cm
10 -15 cm
10 -12 cm
1 ps
1 μs
1 s
Size
Age of Universe

SOME EVENTS OF THE PAST YEAR

Ellis County, Texas Site Chosen for the SSC

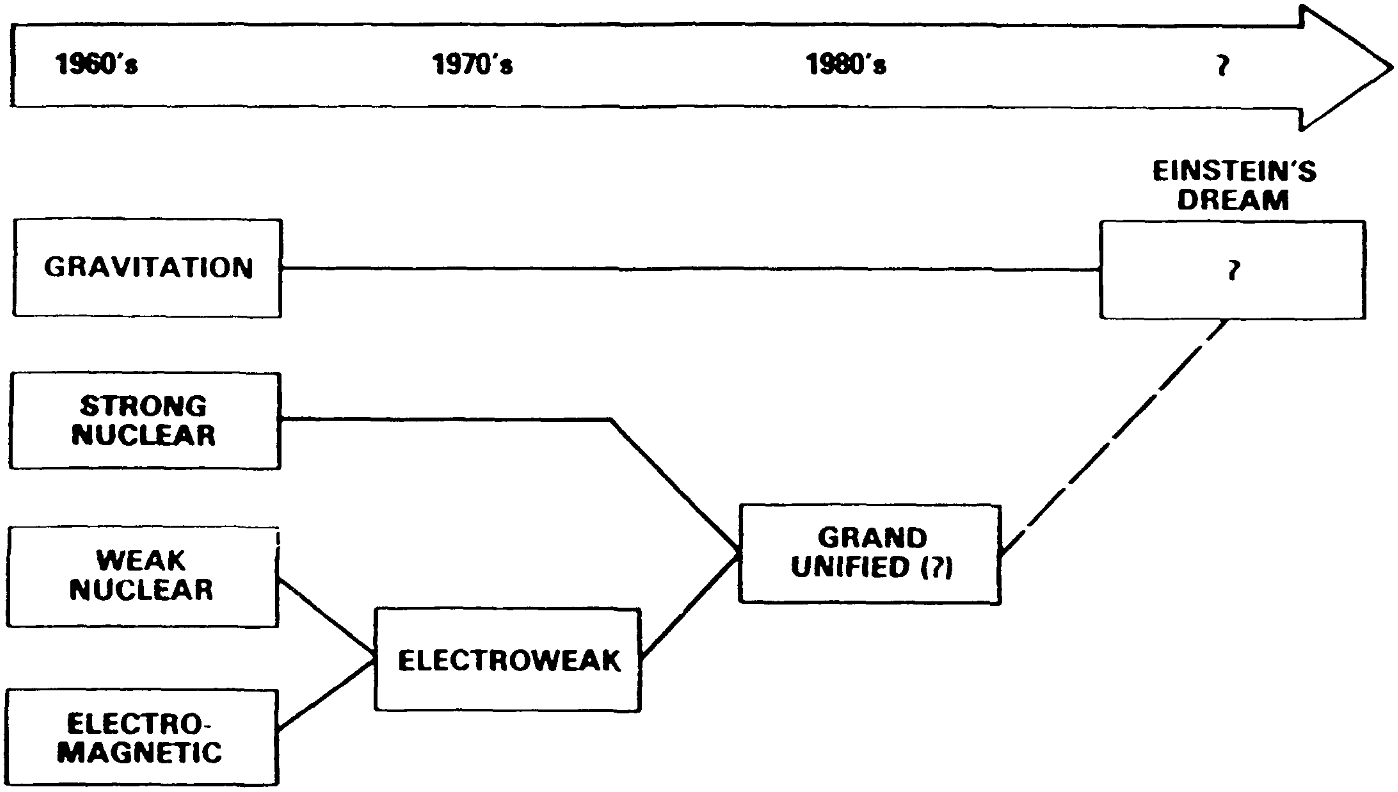
URA Chosen by DOE to be Management and Operating Contractor for the SSC Laboratory

SSCL Begins to Mobilize in Texas

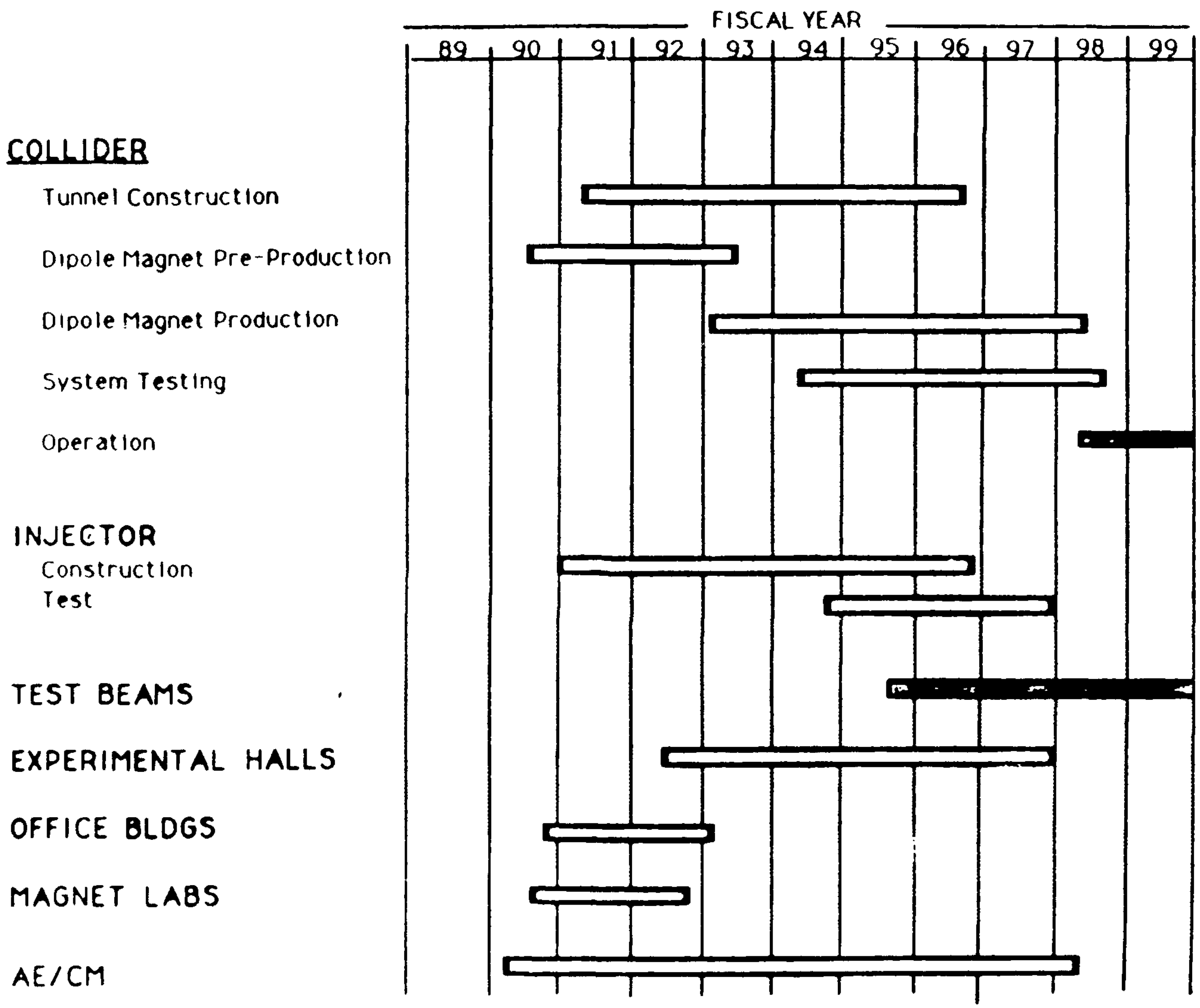
Congress Appropriates and President Approves $225M FY90 Budget for SSC to Begin Construction Starting Oct. 1, 1989

Final Footprint Recommended to DOE & State of Texas

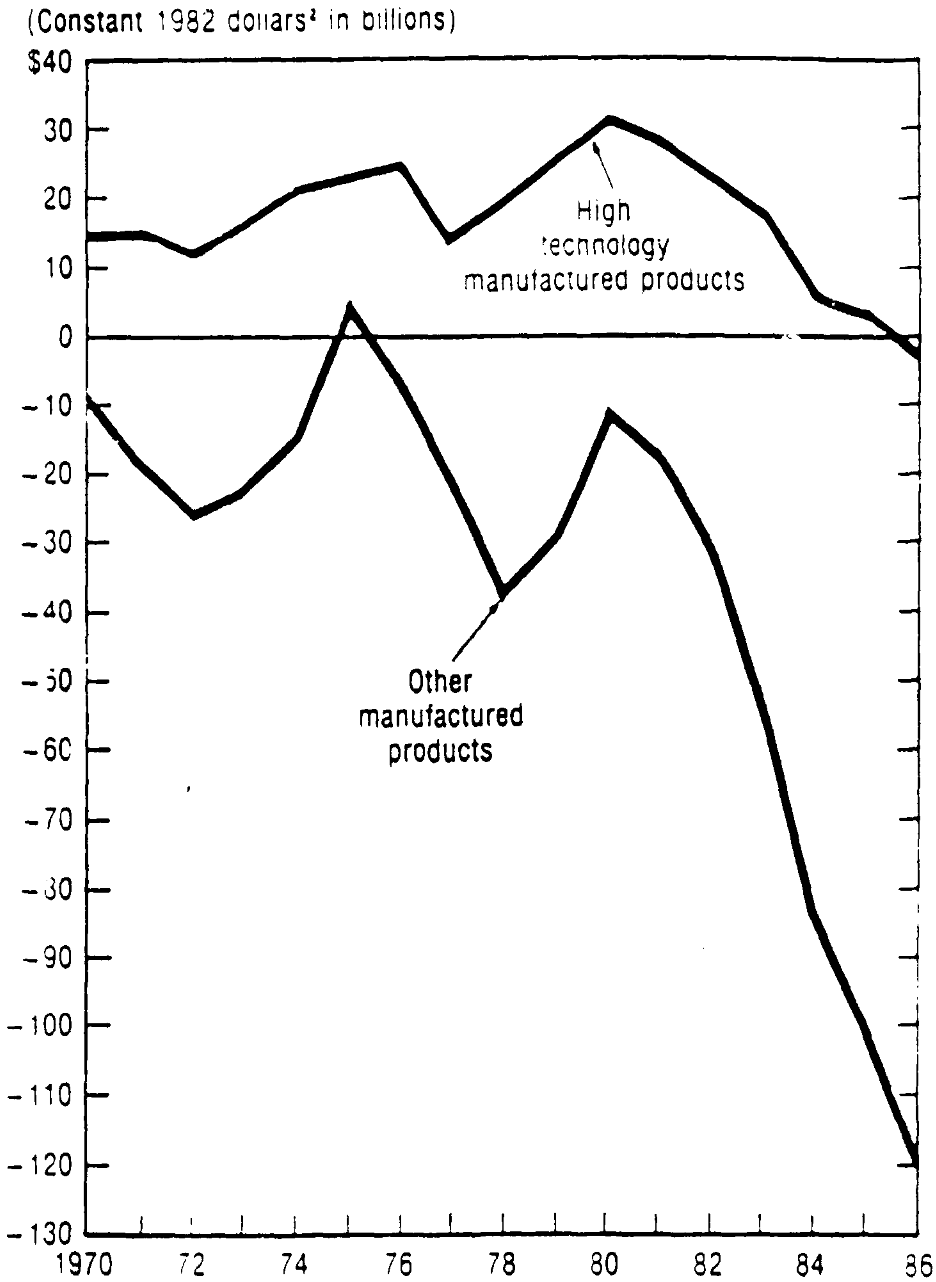
High Energy Physics
Unification of Forces



SSC Project Schedule



U.S. Trade Balance[1] in High-Technology and Other Manufactured Product Groups

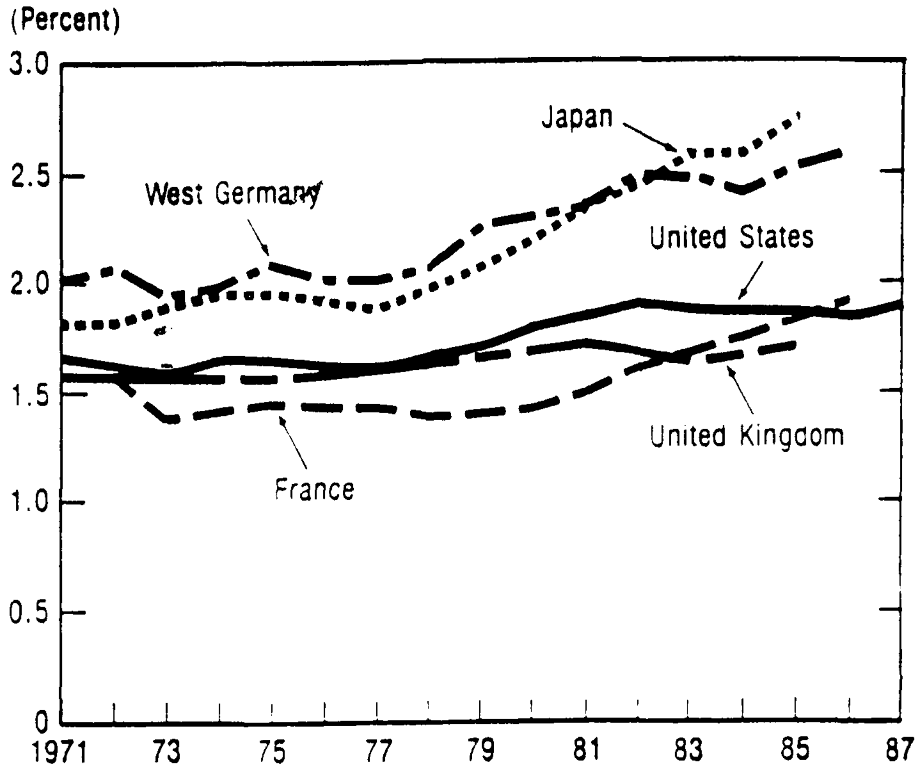


[1] Exports less imports.

[2] GNP implicit price deflators used to convert current dollars to constant 1982 dollars.

See appendix table 7-1 and p. 124 Science & Engineering Indicators — 1987

Non-Defense R&D Expenditures as a percent of GNP, by Country



See appendix table 4-3 and p. 77

Science & Engineering Indicators — 1987

Dr. James King
Jet Propulsion Laboratory

The Use of Charge Coupled Devices in the Remote Sensing from Space

James King, Jr.

Jet Propulsion Laboratory
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Introduction

The primary mission of the Jet Propulsion Laboratory is the scientific investigation of the Solar System with particular emphasis on the planets, including Earth. Remote sensing systems play a major role in the investigation by providing optical images of the planets that contain detailed information on their formation and structure. In early planetary investigations, Vidicon tubes were the principal detectors in imaging systems. With the discovery of Charge Coupled Devices (CCDs) in 1970 by William S. Borden and George E. Smith of Bell Laboratories, it became clear to JPL engineers that such devices were ideal detectors for space imaging systems.

Operation

Charge Coupled Devices operate on the principal of the transferral of all of the mobile electric charges stored within a semiconductor storage element to a similar adjacent storage element by the external manipulation of voltages. These mobile electrons can be generated by photons impending on the semi-conductor surface. The quantity of the stored charge in the mobile packet can vary widely depending on the applied voltages and on the capacitors of the storage element. Because of the conversion of photons to electrons, the amount of electric charge in each pixel (picture element) represents original information in the light source. An elegant analogy by Jerome Kirstian of the Carnegie Institute of Washington is often used to describe how a CCD works (See Fig. 1). Imagine an array of buckets covering a field. After a rain storm, the buckets are sent by conveyor belt to a metering station where the amount of water in each is measured. Then a computer displays a picture of how much rain fell on each part of the field. In a CCD system the rain drops are photons and the field is the semi-conductor silicon surface. The buckets are electron-collecting zones of low electric potential created below an array of electrons formed on the surface of a thin wafer of the silicon. When a photon strikes the silicon, it gives rise to a

displaced electron and the hole created by the temporary absence of the electron from the crystalline structure of the silicon. When the photon creates an electron-hole pair, the electron is immediately collected in the nearest potential well whereas the hole is forced away from the well and eventually escapes back into the substrate.

A more technical description of how a CCD operates was developed by Kirstian and Morely Blouke. They viewed a CCD imager as an array of serial shift registers (See Fig. 2). The image-forming section is covered with closely spaced columns called channels. The channels are separated from one another by narrow barriers called channel stops which prevent the charge from moving sideways. Each channel is in turn subdivided along its length into pixels by a series of parallel electrodes, called gates, which run across the device at a right angle to the channels. Each row of pixels is controlled by one set of gates. A picture is read out of the device by a succession of shifts through the imaging section with all the rows simultaneously moving one space at a time through the body of the device. At each shift the last row of pixels passes out of the imaging section through an isolated region called a transfer gate into an output shift register. Then, before the next row is transferred the information is moved along the output shift register, again one pixel at a time, to an amplifier at the end where the charge in each pixel is measured. This final step constitutes a measurement of the original light intensity registered in the pixel. The technique for moving the electric charge about in this way is called charge coupling and that is how devices operating on this principle got their name.

In effect the pattern of light falling on a CCD imager builds up an electron replica of itself as more electrons are created and collected where the light is brightest. The basic physics of the process is quite linear: doubling the number of photons at any pixel will double the number of electrons, until the potential well corresponding to that pixel is finally filled with electrons.

A third way of viewing the operation of a CCD is through the use of the mechanical analog first proposed by Amelio (See Fig. 3). Imagine a machine consisting of a series of three reciprocating pistons with a crankshaft and connecting rods to drive them. On top of one or more of the pistons is a fluid. Note that rotating the crankshaft in a clock-wise manner causes the fluid to move to the right whereas rotating the crankshaft in a counter clock-wise manner will cause the fluid to move to the left. Since this takes three pistons to repeat the pattern, this arrangement is called a three-phased system. If it is desirable to move the fluid in one direction only, a two-phased system can be devised by imposing an asymmetry on

the piston design (See Fig. 4). Regardless of the direction of rotation, the fluid now advances to the right.

Fabrication

The CCD is fabricated on a substrate on high-resistivity p-type silicon: material in which the main charge carriers are positively charged electron holes. The first step in the creation of the channel stops is by diffusing boron ions through a mask into the exposed part of the silicon substrate and then growing a thick layer of silicon dioxide in those areas. Next the "buried" channels are created by implanting phosphorus ions in the area not covered by the thick dioxide. The phosphorus ions extend some 2,000 or 3,000 angstroms into the silicon. The phosphorus converts the area below the surface into an n-type semiconductor: one in which the main charge carriers are negatively charged electrons. The pn-diode structure so formed localizes the potential well at a position far from the interface between the silicon substrate and the superimposed layer of insulating silicon dioxide. The purpose of the buried channels is to enable the device to transfer a charge more efficiently by keeping the signal electrons away from the interface between the silicon and the silicon dioxide where they can become trapped doing the charge transfer.

The next step in making the CCD imager is to build the electrodes for collecting and moving the charge. After the formation of the buried channels, a layer of silicon dioxide, 1,200 angstroms thick, is thermally grown on the surface to provide an insulating base for the electrodes. A layer of polysilicon, 5,000 angstrom thick, is then grown on top of the oxide layer and is heavily "doped" with phosphorus to increase its conductivity. The first set of electrodes is made from the polysilicon layer by removing unwanted material by means of a standard photolithographic technique. The unprotected gate oxide between the electrodes is etched off and a new gate oxide of the same thickness as the original one is grown over the exposed channel. Simultaneously, a somewhat thicker oxide layer is grown over polysilicon to electrically isolate the first set of electrodes from electrodes that are later formed over them.

A second layer of polysilicon is then grown, doped and patterned to form the second set of electrodes. This set is followed by another etch-and-regrow cycle and by the deposition and doping of a third level of polysilicon from which a third and final set of electrodes is made. Finally a pattern of aluminum strips is formed by vapor-depositing aluminum over the entire surface and then defining the leads photolithographically. The aluminum makes

electrical contact with the diodes and the polysilicon gates, and it leads to peripheral bonding pads where the chip can be connected with its external control circuitry. Two serial output registers are provided; one at the top of the array and one at the bottom so that the image can be read out in either direction.

Application to Remote Sensing

The Jet Propulsion Laboratory has utilized CCDs in two major flight instruments; the Space Telescope Wide-Field Planetary Camera and the Galileo Solid State Imaging Subsystem. Figure 5 shows a cutaway view of the Wide-Field Planetary Camera. This instrument, as its name suggests, can be operated in either of two modes: as a wide-field camera or a higher-resolution camera suitable for, among other things, planetary observations. In each mode the detector system consists of four CCDs microelectronic silicon chips that convert pattern of incident lighting to a sequence of electrical signals. Each chip is a square measuring almost 1/2 inch on the side and is subdivided into arrays of pixels with 800 pixels on a side. A single chip therefore has a total of 640,000 pixels and a four-part mosaic image, formed by a set of four CCDs, has more than 2.5 million pixels. Each pixel *yields an electrical signal proportional to the number of photons, or quanta of* electromagnetic radiation, reaching it during an exposure.

In the wide-field mode the camera has a square field of view 2.67 arc minutes on a side, the largest field of any of the instruments on the Space Telescope. Each pixel in this mode subtends an angle of 1/10 arc second. In a sense, the Wide-Field Camera compromises the angular resolution of the Space Telescope in order to provide a field of view large enough for the study of extended sources such as planetary nebulas, galaxies and clusters of galaxies. The field of view is much smaller than the field that can be recorded on a photographic plate by a ground-based telescope. In the Space Telescope the field is limited by the size of the microelectronic detectors available for remotely acquiring, storing and digitizing pictures. The CCDs for the Wide-Field/Planetary Camera have more pixels than any other CCDs used for astronomical purposes.

In the planetary mode, the square field of view of the camera covers an area of sky by a fifth as large as it does in the widefield mode: the field in the planetary mode measures 67.7 arc seconds on a side and an individual pixel subtends an angle of .043 arc second. The planetary camera takes advantage of almost a full resolution of the optical system while providing a field of view that is more than adequate for full-disc images of the planets. The

high sensitivity of the CCD detector system makes possible the short exposure time required for certain planetary observations.

Galileo is a spacecraft mission to Jupiter designed to study the planet's atmosphere, satellites and surrounding magnetosphere. The spacecraft was launched in October, 1989 by the Space Shuttle. The mission was named for the Italian renaissance scientist who discovered Jupiter's major moons with the first astronomical telescope. The mission will be the first to make direct measurements from an instrumented probe within Jupiter's atmosphere and the first to conduct long-term observations of the planet and its magnetosphere and satellites. It will be the first orbiter and atmospheric probe for any of the outer planets. The solid-state imaging camera on Galileo is designed to observe Galilean satellites at a l-kilometer resolution or better. It contains a 800 x 800 CCD detector unit, operating in the single or virtual phase, the frequency range is from 3,500 to 10,000 angstroms. The camera was designed and the CCDs were developed to tolerate the intense radiation within the Jovian environment. Figure 6 shows the Galileo Solid-State Imaging Subsystem camera and Fig. 7 summarizes both the Wide-Field Planetary camera and the Galileo solid-state imaging CCD components.

Conclusion

The discovery of Charged Couple Devices has improved the ability of spacecraft to do precise remote imaging in space. As their development continues the sensitivity in resolution in CCD cameras will allow much more details to be observed from both planetary and interstellar bodies.

References

1. James Janesisk and Morley Blouke, "Sky and Telescope", September, 1987.
2. Jerome Kirstian and Morley Blouke, "Scientific American", October, 1982.
3. Gilbert F. Amelio, "Scientific American", February, 1974.

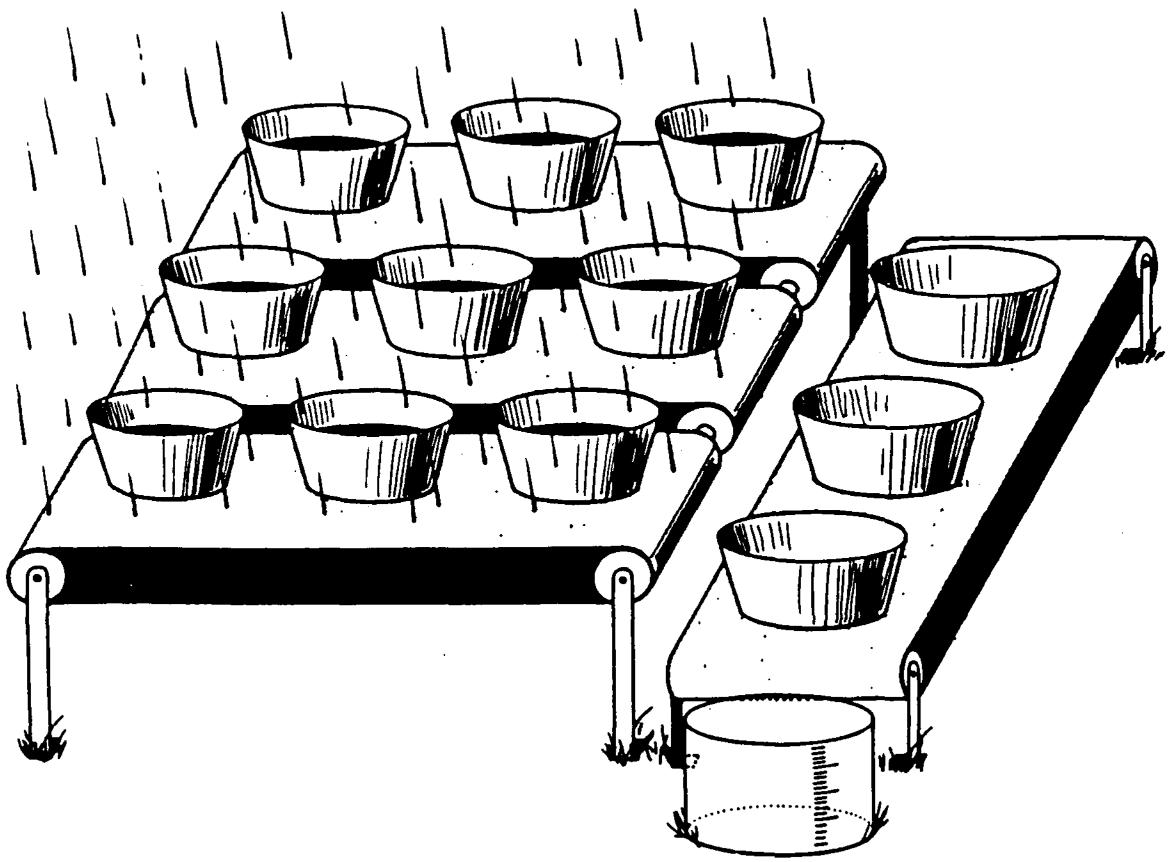

Fig. 1 Determining the brightness distribution in a celestial object with a charge-coupled device can be likened to measuring the rainfall at different points in a field with an array of buckets. Once the rain has ceased, the buckets in each row are moved horizontally across the field on conveyor belts. As each one reaches the end of the conveyor, it is emptied into another bucket on a belt that carries it to the metering station where its contents are measured.

Artwork by Steven Simpson

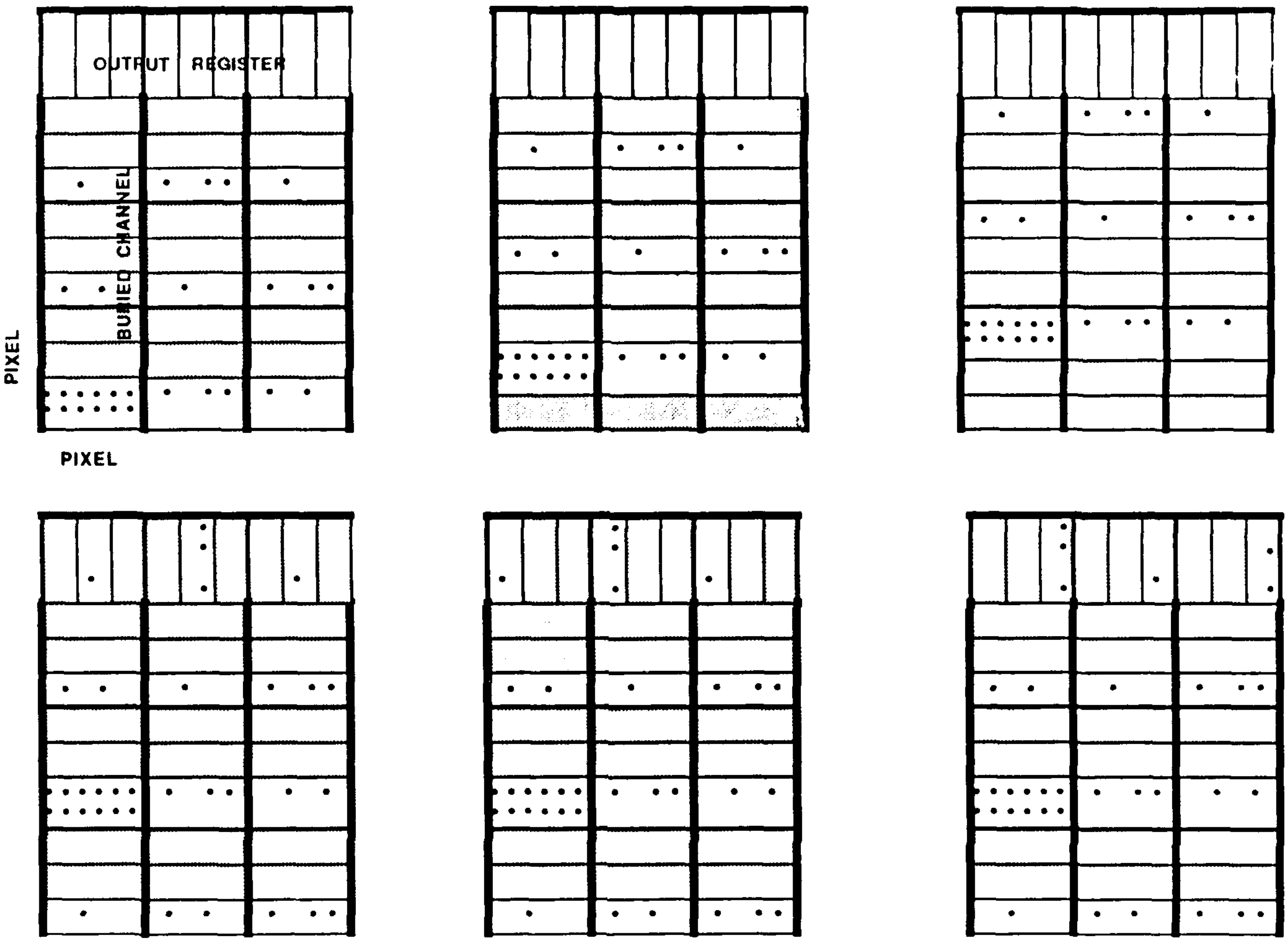

Fig. 2 Operating principle of the CCD imager is depicted in this sequence of schematic diagrams, each of which corresponds to a small segment near the top edge of the device.

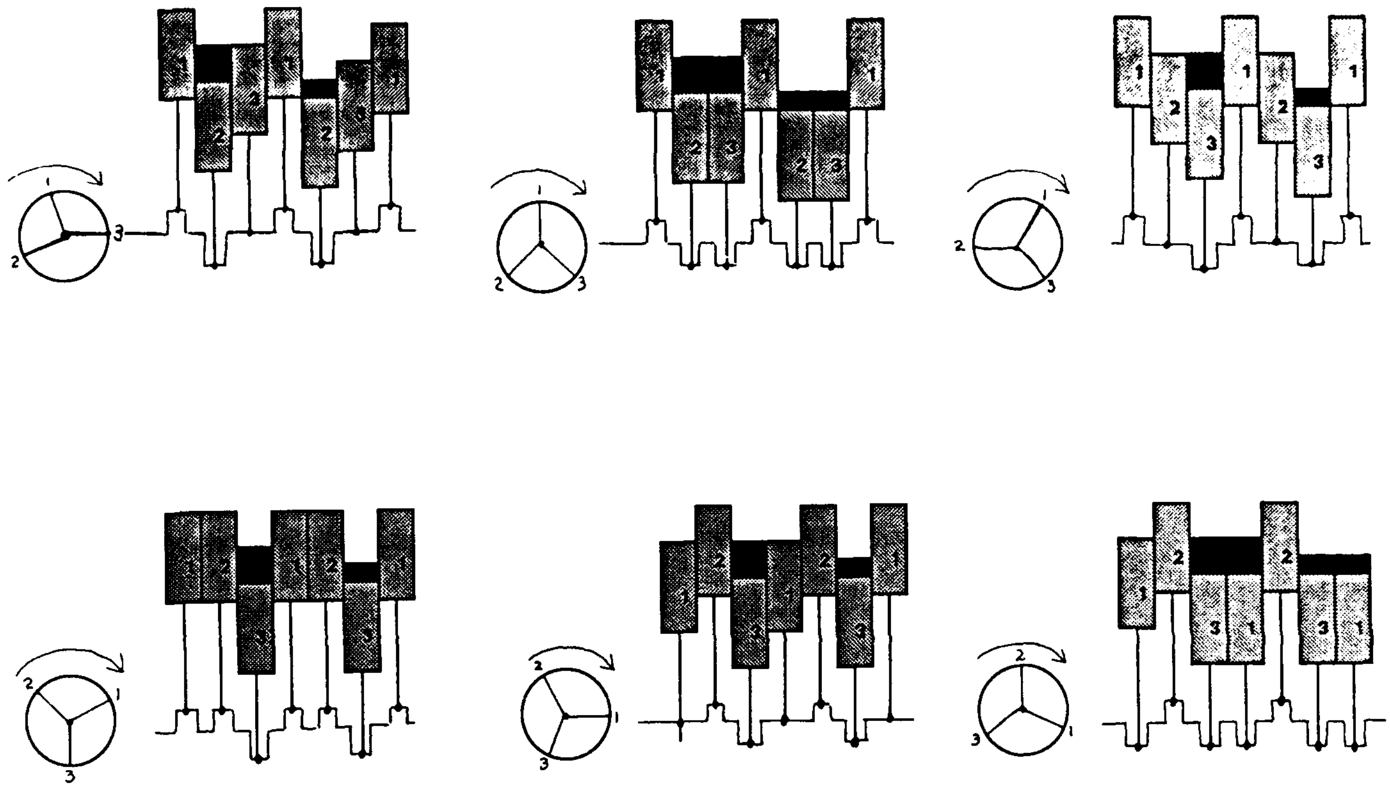

Fig. 3 Symmetrical mechanical analogy of the operation of charge coupled devices. The pistons represent external voltage and the fluid on top of the pistons represent movement of electrons.

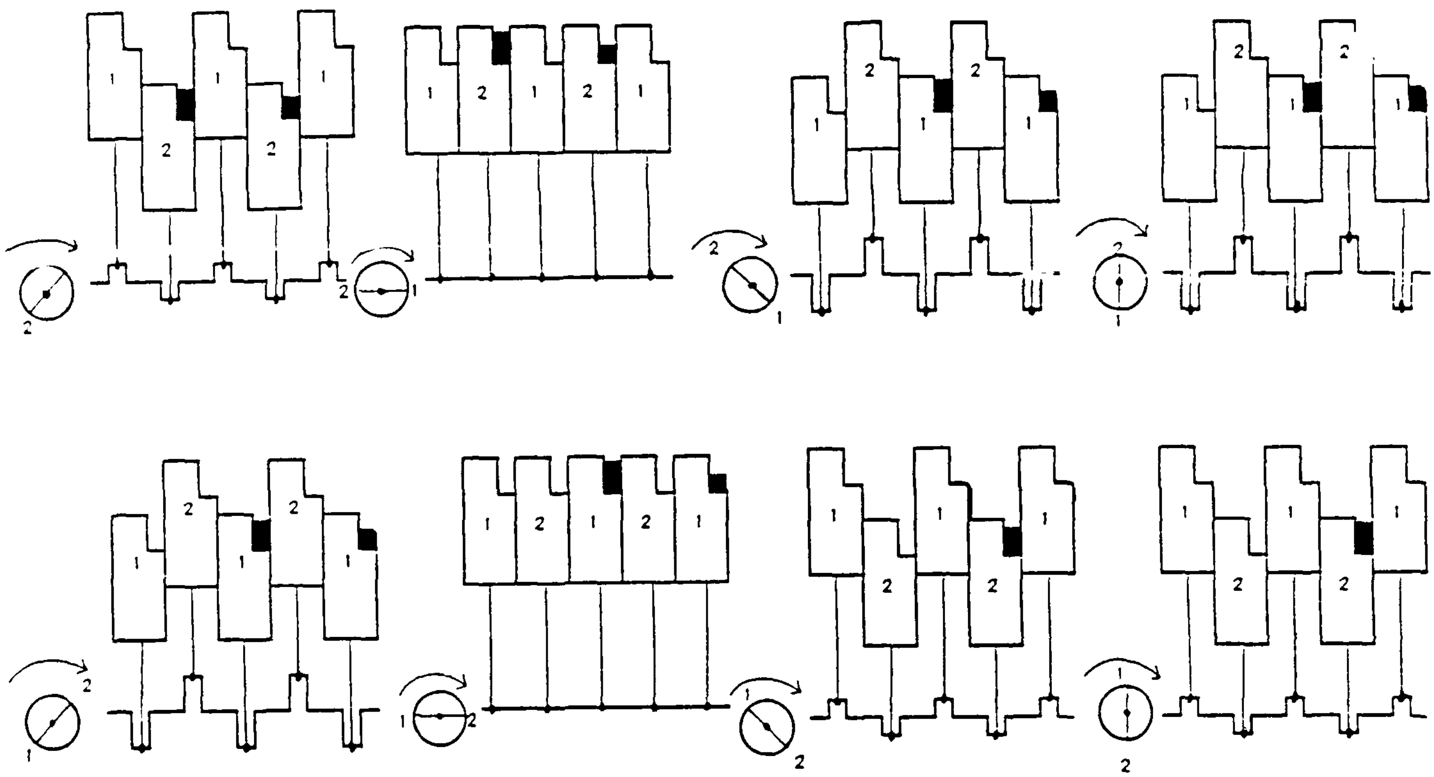

Fig. 4 Asymmetrical mechanical analogy of the operation of a two-phase CCD system.

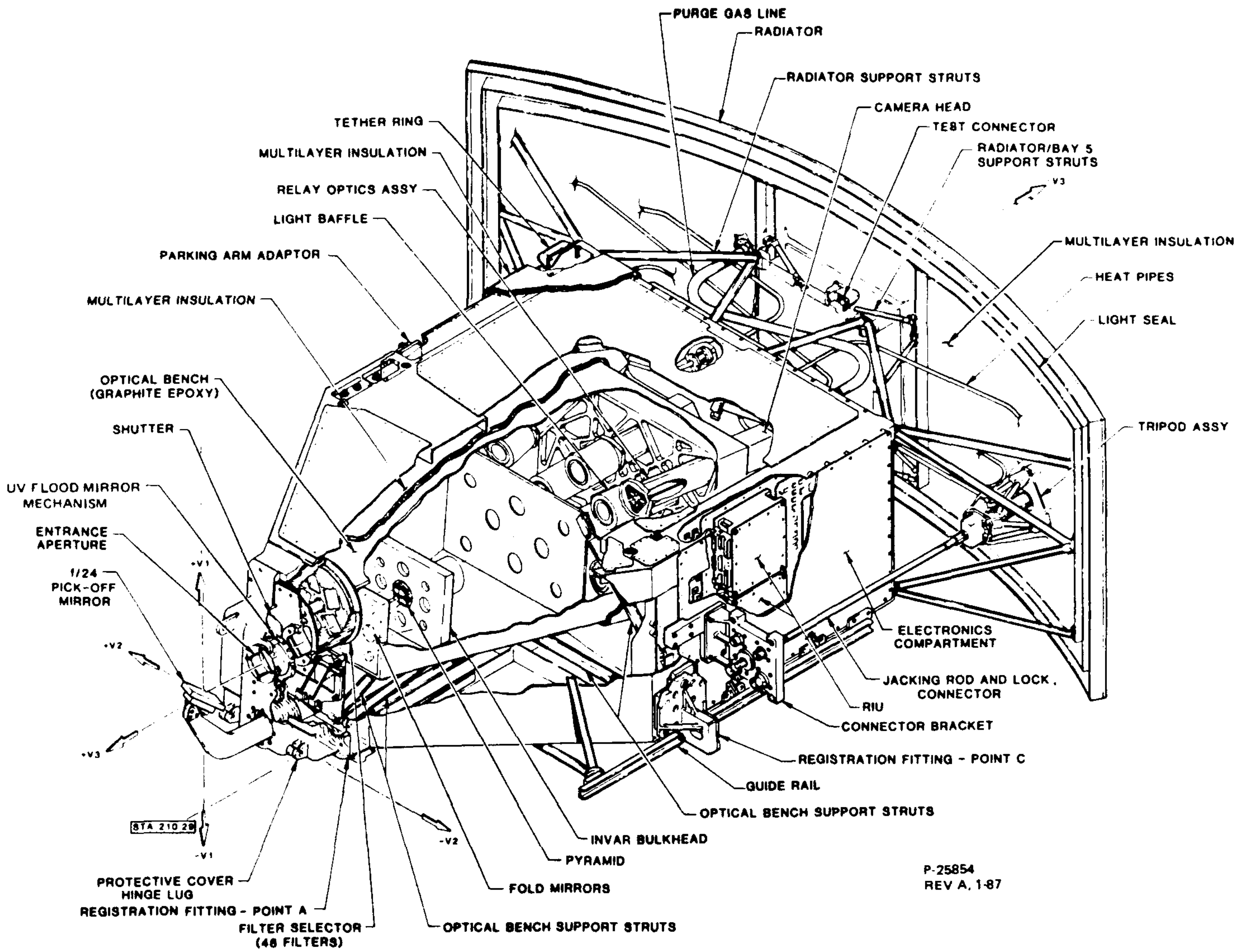

Fig. 5 Wide-Field/Planetary Camera (cutaway view showing interior).

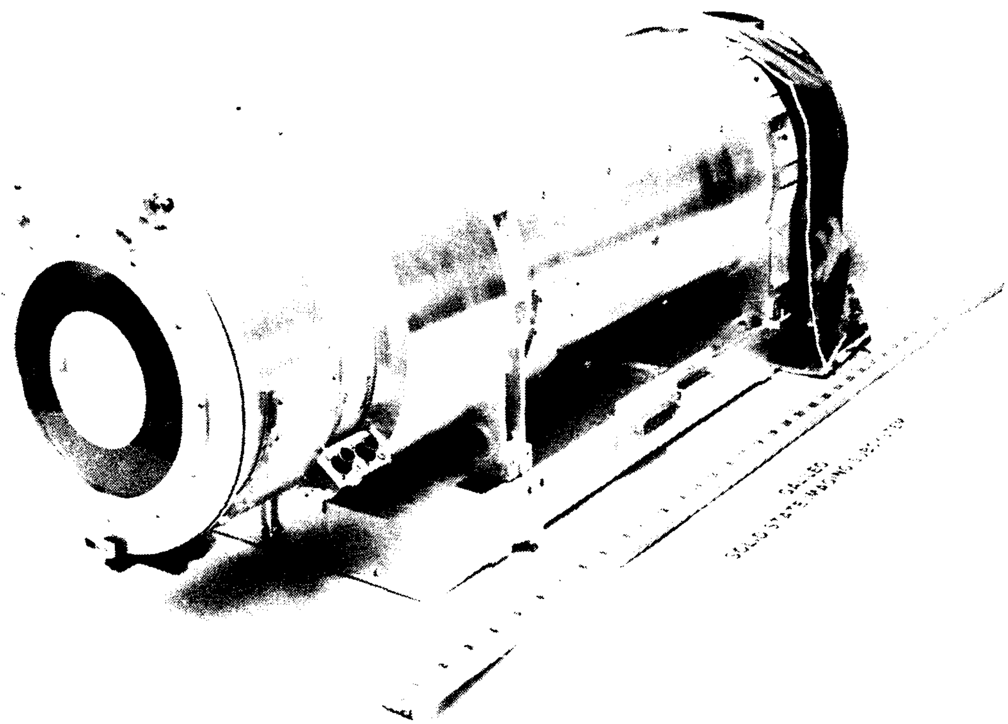

Fig. 6 Galileo Solid-State Imaging Subsystem Camera.

JPL

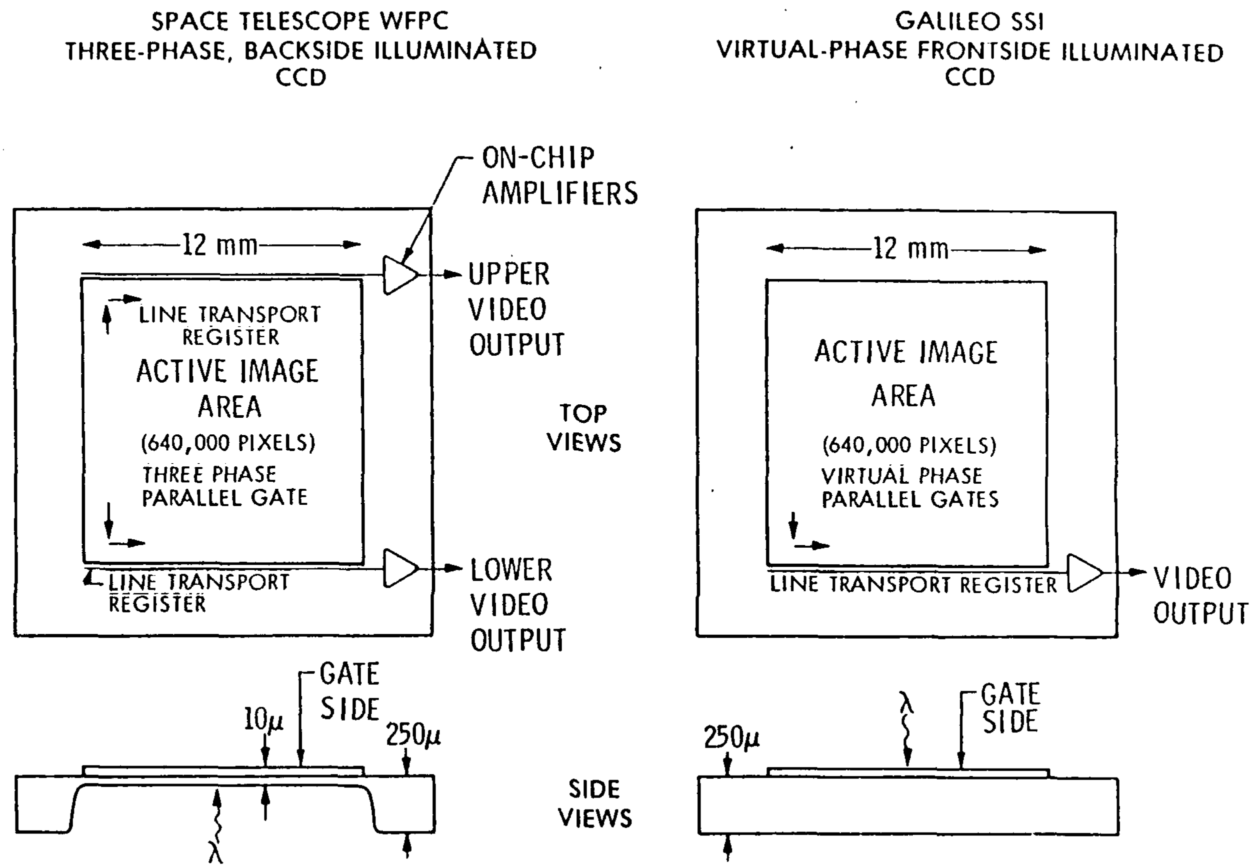

Fig. 7 CCD Basic Concepts

Scientific Research in the Soviet Union

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Abstract

I report on the scientific aspects of my US/USSR Interacademy Exchange Visit to the Soviet Union. My research was conducted at three different institutes: the Lebedev Physical Institute in Moscow, the Leningrad Nuclear Physics Institute in Gatchina, and the Yerevan Physics Institute in Soviet Armenia. I include relevant information about the Soviet educational system, salaries of Soviet physicists, work habits and research activities at the three institutes, and the relevance of that research to work going on in the United States.

Introduction

During the period December 28, 1988-June 25, 1989, I participated in the US/USSR Interacademy Exchange Program administered by the National Research Council. Under the terms of the program, I was accompanied by my wife, W. Estella Johnson, and two daughters, six year-old Sharifa Mtingwa and nine year-old Makazi Mtingwa. My itinerary is given in Appendix A.

At the Lebedev Physical Institute I was involved in theoretical investigations into the use of plasmas to accelerate electrons for possible use in the future generation of electron linear colliders. With Leonid Gorbunov, a distinguished plasma theoretician, I wrote a review article which summarizes the current state of affairs in the use of these plasma acceleration techniques. Our paper should be already published in the popular Soviet journal called *Knowledge,* which is written for the layman. This journal is published once per year in the form of a book and summarizes exciting new areas of scientific investigations.

At the Leningrad Nuclear Physics Institute, I studied the theory of CP (charge conjugation-parity) violation and possible tests of CP violation by studying the heavy B mesons. Jointly with Mark Strikman, I proposed a new scheme for generating the necessary number of B mesons for unlocking the mystery of CP violation (see *Phys. Rev. Lett., vol. 64,* p. 1522, 1990).

At the Yerevan Physics Institute, I continued my work with Mark Strikman, who also visited Yerevan while I was there. Also, I continued my attempts to develop the theory of ferrites as possible media for wakefield acceleration experiments. In addition, I held many discussions with Yerevan physicists, as well as with other physicists who visited Yerevan, about their various programs of research involving new methods of accelerating charged particles.

In the next section, I describe the educational system which one must complete in order to become a scientist in the Soviet Union. I include information on Soviet scientific salaries. In Sections III-V, I describe work habits of Soviet physicists, their research activities, and my collaborations at the Lebedev Physical Institute, the Leningrad Nuclear Physics Institute, and the Yerevan Physics Institute, respectively. Finally, in Section VI, I comment on my research conclusions and the relevance of Soviet research activities to research ongoing in the United States. In Appendix A I give a full itinerary of my visits, and in Appendix B I give a listing of literature which I acquired.

The Soviet Educational System and Scientific Salaries

A chart of the Soviet educational system looks as follows:

Primary & Secondary School	*University (Undergraduate)*	*Aspirantura (Graduate)*	*Doctorate*
10 years	5-6 years	3-7 years	7-15 years
From ages 7 to 17	Finish about age 23	Finish at 26-30	Finish at 37-45

Upon completion of the Aspirantura (Graduate studies), the student is called a Candidate, unlike our designation of Doctor. In the Soviet Union Doctor has a more substantive meaning. About 10% of the candidates go on to achieve the title of Doctor, which is based upon years of excellent scholarly research. After achieving the title of Doctor, a few go on to attain the title of Professor, which is partly based upon supervising the research of about

five Aspirants (Graduate students) enabling them to become Candidates.

The salary structure of Soviet scientists goes roughly as follows:

I. Aspirant (Graduate student working on thesis problem)- 100 Rubles/month

II. Mladshy Sotrudnik (Junior co-worker, not necessarily a candidate, so he/she may be without a Graduate degree)- 150-200 Rubles/month

III. Nauchny Sotrudnik (Scientific co-worker, should be a candidate) - 200-250 Rubles/month

IV. Starshy Sotrudnik (Senior co-worker) Without title of Doctor-250-300 Rubles/month With title of Doctor-350 Rubles/month

V. Vedushchy Sotrudnik (Outstanding co-worker)- 400-500 Rubles/month Maximum paid only to Chiefs of Divisions.

VI. Glavny Sotrudnik (Head co-worker, usually Director of an Institute)-600 Rubles/month

To convert to U.S. dollars, the official exchange rate during my visit was 1.65 US dollars per ruble. The salaries seem very low but typical expenses are not very high. For example, an apartment can cost twenty-five rubles/month or less, although they are usually not available. The average wait for new couples to obtain their own apartments is about fifteen years. The rule is for young couples to live with their parents.

What can be said about Soviet scientists is that they work very hard under extremely adverse conditions and they are only minimally compensated for their efforts via salary, living conditions, medical care, etc.

The Lebedev Physical Institute (December 29,1988-February 27, 1989)

At the Lebedev Physical Institute, my official hosts were Professors Andrei Kolomensky and Andrei Lebedev. But as for my research, I collaborated with three of their plasma theoretical physicists to whom Kolomensky and Lebedev introduced me. They were led by

Leonid Gorbunov who received the State Prize in 1987 for his theory of the nonlinear dynamics of high frequency wave processes in fully ionized plasmas. He is also a Professor of Physics at Patrice Lumumba People's Friendship University. The other two were a Georgian physicist named Ramaz Ramazashvili and a Russian physicist named Viktor Kirsanov.

Every year a Soviet journal, *Knowledge,* is published in the form of a book and seeks to explain to the layman current areas of scientific research. Someone from that journal asked Gorbunov and me to write a mini-review of the plasma wakefield acceleration techniques currently underway in laboratories such as my own at Argonne National Laboratory. The issue containing our article should already be published.

In the plasma wakefield accelerator, a dense low energy bunch of electrons (called the driver) traverses a cold plasma leaving an electromagnetic field in its wake. A lower density second bunch of electrons (called the witness pulse) can then be accelerated by the driver's wakefield. Theoretically, the rate of acceleration for the second bunch can exceed 100 million electron volts (MeV) per meter; this is to be compared with the 15-17 MeV per meter which is obtainable at the Stanford Linear Accelerator Center (SLAC), the world's most powerful electron linear accelerator. In a slightly differently scheme preferred by Gorbunov, the wakefield can be generated by a single short intense laser pulse. Gorbunov has a long history of studying the effects of high frequency electromagnetic waves propagating through plasmas.

In practically all theoretical discussions, the plasma density is assumed to be homogeneous. In our investigations at the Lebedev Institute, we considered the possibility of shaping the profile of the plasma density so as to maximize the energy obtainable by the witness electron pulse. Typically one wants to position the witness pulse on the crest of the electromagnetic wakefield wave profile. But as the witness pulse is accelerated, it begins to roll down the crest of the wave toward the decelerating phase. We found that by changing the plasma density profile, one can alter the wave profile so as to fix the witness pulse at the crest of the wakefield. Our results are contained in a paper to be published in one of the Lebedev Institute journals. The paper is entitled, *Increasing the Effectiveness of the Acceleration of Electrons by a Wave of Charge Density by Special Profiling of the Plasma Density.* The precise formula for how the plasma density should be shaped is given in the paper.

As an example, we considered the case of a single laser pulse of length 10^{-13} second generating a wake in a plasma with nominal density 10^{15} electrons per cubic centimeter. We found that for the case of uniform plasma density, the effective length over which a 50 MeV witness pulse can be accelerated is 300 centimeters, and it can attain an energy of 3 GeV. On the other hand, if the plasma density profile is shaped according to the prescription given in our paper, the effective length of acceleration is increased to 10 meters and the final energy of the witness pulse can be increased to 10 GeV.

While in Moscow, I gave three seminars on the new wakefield acceleration techniques: two at the Lebedev Institute and one at Patrice Lumumba People's Friendship University. One of my seminars at the Lebedev Institute seemed to stimulate Andrei Lebedev to want to perform similar experiments in their microtron, located about 20 kilometers outside Moscow. Their microtron accelerates 300 milliamperes of electrons to 24 MeV with a pulse train duration of 6 microseconds. Lebedev thinks that they can produce pulses short enough (roughly 6 millimeters) and with enough charge to perform useful wakefield experiments.

The normal working conditions for the physicists at the Lebedev Institute were rather difficult. As is the case throughout the Soviet Union, office space was extremely limited. Small offices, in which we would place only one person in the U.S., would contain three or four people. Also, office supplies were very limited. This included paper for performing calculations, xeroxing machines, etc. And as is the case in all Soviet research facilities, computers were not routinely available. Moreover, personal computers were a rarity. Unlike the situation in Leningrad (see below), the physicists at the Lebedev Institute worked a rather normal workday and usually worked in their offices rather than at home.

I felt that my collaboration with Gorbunov, Kirsanov, and Ramazashvili was a good one and could have significant impact if plasma wakefield acceleration is implemented in the future for high energy accelerators.

The Leningrad Nuclear Physics Institute (February 28, 1989-May 5, 1989)

At the Leningrad Nuclear Physics Institute (LNPI), my official host was Professor Alexei Anselm, Head of the Theory Department, and a theoretical high energy physicist whom I met several years ago during his visit to the Fermi National Accelerator Laboratory in Batavia, Illinois. I was a staff physicist there at the time.

The scientific activity of the LNPI covers the following areas:

- Elementary particle physics
- Nuclear and atomic physics
- Physics of condensed matter
- Molecular and radiation biophysics

All the internal activity at the Institute is grouped into divisions and laboratories according to scientific interest. The following is a current list of divisions and laboratories:

- High Energy Physics Division
- Neutron Research Division
- Theoretical Physics Division
- Molecular and Radiation Biophysics Division
- Condensed State Research Division
- Electronics and Automatization Division
- Radiation Detector Division
- Central Computer Division
- Mini- and Microcomputer Division
- Reactor Physics and Technology Division
- Accelerator Physics and Technology Laboratory
- Radiation Physics Laboratory
- Cryogenics and Superconduction Laboratory
- Informational Computing Systems Laboratory
- Laboratory of Holographic Information and Measuring Systems

The main research facilities of the LNPI are a 1 GeV protron synchrocyclotron, an 18 megawatt nuclear reactor WWR-M, and a 100 megawatt high flux nuclear reactor PIK (under construction).

The theoretical high energy physicists with whom I worked at LNPI rode the train to work only once per week. The other days of the week they would work at home or meet in small groups at their homes. In addition, they held a regular weekly seminar on Mondays in a building in Leningrad called the *House of Scientists*.

Traveling to work once per week was for two reasons. First and most importantly, there simply were not sufficient offices for the large number of physicists who worked at LNPI. So the same offices would be used by high energy theorists one day, by solid state theorists another day, and so forth. Secondly, the Institute was located in Gatchina, about 30 kilometers outside of Leningrad where practically all of the physicists lived. The commuting time from home to work was about 2 hours. So, about 4 hours were lost just in the commute to and from work. The high energy theorists typically went to Gatchina on Thursdays. Whenever scientists such as myself were visiting the institute, they arranged to have them ride to and from work in a special van. And there was usually room for some of the Leningrad scientists to ride as well. However, I stopped requesting the van after a while, because I enjoyed the rather lively political discussions on the train enroute to work, especially since I was in Leningrad during voting for the first-ever popularly elected Syezd (Congress) which resulted in all Leningrad Communist Party members running for the Syezd being defeated.

Since the high energy theorists went to the office only one time per week, Thursdays usually involved a great deal of running around on bureaucratic errands and visits to the library to read journals and either drop off or pick up xeroxing. As for the xeroxing, it was not a simple matter as in the U.S. Typically, it took at least one week to have an article xeroxed; however, sometimes it would not be ready the following Thursday.

As in Moscow, the supply of office equipment was minimal, and paper was in short supply. I was told the reason being, that with the shortage of housing, top priority for wood was for construction. As a consequence, writing paper was not plentiful and used computer paper was often substituted for napkins in the cafeteria.

The big main-frame computers were pretty much reserved for the experimentalists. As a consequence, theoretical calculations tended to be slow and laborious, usually done by hand. This forced the theorists to specialize themselves to be able to do certain kinds of difficult calculations, so that if someone else needed something to be done, they knew who was best suited to do the calculation by hand.

While at LNPI, I studied CP violation theory with a young physicist named Nicolai Uraltsev. However, my main work was with Mark Strikman, who just had received his Doctorate the previous fall. Strikman and I wrote a paper entitled, B *Factory Via Conversion of 1 TeV Electron Beams into 1 TeV Photon Beams*. First, we derived

formulae which describe the interaction of laser beams with electron beams. Then, specializing to the case of 1 TeV electron beams from the future generation of electron linear accelerators, we calculated the production rate of backscattered 1 TeV photons, and using these photons, we showed that it is possible to organize the photoproduction of beauty particles so as to measure 109 B meson pairs per year. This is the number that theorists have argued is sufficient to study rare B meson decays and CP violation. At the conclusion of my Soviet trip I presented our results at the *Workshop on B-Factories and Related Physics Issues* held in Blois, France, June 26-July 1, 1989.

In other theoretical research at the Institute, A. Anselm and A. Johansen studied violations of the Adler-Bardeen theorem in multi-loop order of perturbation theory resulting from photon-photon scattering. L. Frankfurt and M. Strikman studied short-range correlations in nuclei, involving light-cone quantum mechanics of the deuteron, structure of the single nucleon spectral function at large momenta, color screening effects in nuclear structure, and new options for studying microscopic nuclear structure at high energy facilities of the 1990's. Y. Dokshitzer, V. Khoze, and S. Troyan studied coherence phenomena and physics of QCD jets. Ya. Asimov, V. Khoze, and N. Uraltsev studied mixing and CP violation in the decays of B mesons. Yu. Petrov studied muon catalyzed fusion.

For the experimental program, there was a big effort to use their 1 GeV proton synchrotron to study the neutron electric dipole moment, K^+ lifetime, proton-neutron elastic scattering, proton-proton elastic scattering, and search for narrow dibaryon resonances. The Director of the Institute, Professor Alex Vorobyov, and co-workers were part of a big collaboration at the U.S. Fermi National Accelerator Laboratory to measure the Σ^- magnetic moment with FNAL Experiment E-715.

I gave one colloquium at LNPI in their beautiful auditorium in the main administration building. It was similar to the one I gave at the Lebedev Institute on new methods of accelerating charged particles using wakefields. Although no one there was involved in similar investigations, there was a great deal of interest in our results.

While in Leningrad, Anselm and his wife, Ludmila, were very gracious to me and my family and did everything they could to make our stay both profitable at work and enjoyable in general.

The Yerevan Physics Institute (May 6, 1989-June 1, 1989)

At the Yerevan Physics Institute I continued to make progress on my research project with Mark Strikman of LNPI. Some of the physicists there were able to make useful input into that project. While I was in Yerevan, Strikman also visited there, so we had an opportunity to work together. Also, I continued to work out the theory of using ferrite materials to replace the plasma medium in the wakefield acceleration program.

However, most of my time at Yerevan was spent in discussions with the physicists there involved in both theoretical and experimental studies of new acceleration techniques, such as the plasma wakefield acceleration idea. As for plasmas, the physicists there were mainly interested in nonlinear effects. They want to reduce the charge density of their plasma to twice that of their driver charge density and thereby induce nonlinear plasma oscillations. The Director there, Professor A. Amatuni, thought that they may be two years from performing an experiment, although I got the feeling that it may be even longer.

Their reason for studying nonlinear effects is that these effects may allow the possibility to improve the transformer ratio (ratio of maximum acceleration of the witness pulse to the maximum deceleration inside the driver pulse). They had a theoretical team feverishly studying the nonlinear theory composed of A. Amatuni, S. Elbakyan, E. Lasiev, N. Nagorsky, M. Petrossyan, and E. Sekhpossyan.

For accelerators, Yerevan has a 2 GeV electron synchrotron, soon to be improved to 6 GeV, with a 50 MeV injection linac, soon to be upgraded to 75 MeV. Also, they are building a 150 MeV electron linac carrying 1.5 Amperes which could go up to 300 MeV carrying 0.3 Amperes. The new linac is predicted to be completed by 1993. One of these linacs could be used for their wakefield experiments.

High up on Mt. Aragats at 3200 meters, the Yerevan Physics Institute operates an installation called *Pion* to study cosmic ray physics. The Head of the installation is Professor E. Mamidjanyan. On May 8 they took my whole family on a tour of their facility.

There they hope to identify the hadronic composition and spectrum of cosmic radiation in the energy range 0.5-5 TeV. Also, they hope to investigate the interactions of pions, protons, and neutrons with target nuclei (eg. iron in the detector). They want to measure cross sections and compare with accelerator measurements and with theory, study

quarkgluon structure, and determine the dependence of inelastic pion-nuclei and nucleon-nuclei cross sections on atomic number.

The typical life of the physicists at the Yerevan Physics Institute on the surface was more similar to that of physicists in the States than those in Leningrad and Moscow. One of the administrators there jokingly told me that in the Soviet Union, the further you are from Moscow, the easier life becomes. I found that offices were not as cramped in Yerevan as in Moscow and Leningrad. And the physicists seemed less stressed from their working conditions. On the other hand, almost every Armenian adult's life is consumed by the conflict between Armenia and Azerbaijan. Oftentimes, politics and the workplace were intermingled. It was not unusual for there to be political meetings in the middle of the workday on the lab site concerning the ethnic conflict with the Azerbaijanis. Tensions were extremely high while we were in Yerevan. During one week, public demonstrations were held every night in the center of town with some 200,000 to half a million people participating, although no mention was made of it on the evening news program, *Vremya*.

When word spread that I, as a representative of my Argonne group, was in Yerevan, several physicists from other cities came to hold discussions with me. Quite a few non-Yerevan physicists attended the colloquium which I gave in their main lecture hall. Since my group's work was rather well-known, they mostly wanted to get my impressions of their investigations

My stay in Yerevan was very productive in terms of my research, learning about their programs and discussing my Argonne group's activities.

Discussion and Conclusions

My research collaborations proved to be very successful during my Soviet visit. In Moscow at the Lebedev Institute, we were able to greatly optimize the acceleration of electrons in the plasma wakefield acceleration scheme. As explained above, this involves fixing the witness electron pulse at the maximum acceleration phase so as to avoid phase slippage to the decelerating phase. This is accomplished by shaping the plasma charge density profile according to the prescription contained in our paper as cited in Section III. Also, I had the rare opportunity to co-author a review paper for the popular journal, *Knowledge,* which describes the current interest and investigations into new methods of accelerating charged particles in the plasma wakefield acceleration scheme.

At LNPI in Gatchina, Mark Strikman and I succeeded in describing a scheme which could lead to the production and detection of 109 B mesons pairs per year, which is the number theorists believe is sufficient to study rare B meson decays and CP violation. Unlike other B meson factory ideas, our scheme produces so many B mesons that our main goal was to limit the number the detector has to process.

Finally, at Yerevan I continued my attempts to understand how ferrite materials can be used to replace plasmas as the medium which produces wakefields for charged particle acceleration. Also, I continued my work on the B meson factory with Mark Strikman.

Toward the end of my Soviet visit, I returned to both Leningrad and Moscow to finalize papers with my collaborators before departing for the B meson workshop in Blois, France. Also, I was required to leave the Soviet Union from Moscow.

In general I found that the high energy physics research programs in the Soviet Union were complementary to ours in the U.S. However, it is clear that their experimental high energy and accelerator physics programs are far below par when compared with those in the West. The physicists there complain of the long length of time needed to acquire funding to build equipment and the fact that they have to actually build so much from scratch themselves. This is unlike the situation in the West where so much of the major components are contracted out to private companies.

In theoretical physics, the Soviets fare much better. However, the lack of mainframe computer facilities and personal computers makes life very difficult for them. As a consequence, they play essentially no role in certain areas of physics research, for example computational lattice gauge theory.

However, despite all of their difficulties, the Soviet physicists are highly motivated and quite productive.

APPENDIX A
Itinerary of My Soviet Exchange

- December 29, 1988-February 27, 1989
  P.N. Lebedev Physical Institute
  Leninsky Prospeckt 53
  Moscow

- February 28, 1989-May 5, 1989
  Leningrad Nuclear Physics Institute
  Gatchina
  Leningrad District

- May 6, 1989-June 1, 1989
  Yerevan Physics Institute
  Soviet Armenia

- June 2, 1989-June 14, 1989
  Leningrad Nuclear Physics Institute
  Gatchina

- June 15, 1989-June 25, 1989
  Lebedev Physical Institute
  Moscow

APPENDIX B
Literature Acquired

1. A. Amatuni, S. Elbakyan, and E. Sekhpossyan, *Nonlinear Effects in Plasma Wakefield Acceleration,* Yerevan Physics Institute Preprint No. YPI-935(86), 1986.

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3. A. Amatuni, E. Sekhpossyan, and S. Elbakyan, *Excitation of Strong Longitudinal lVaves in Plasmas by Electron Bunches,* Physics of Plasmas (Short Reports), 12(9), p. 1145, 1986.

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14. L. Gorbunov and L. Anosova, *On Charge Neutralization of an Electron Bunch in a Plasma,* Journal of Technical Phys. 47(6), p. 1150, 1977.

15. L. Gorbunov, V. Kirsanov, S. Mtingwa, and R. Ramazashvili, *Increasing the Effectiveness of the Acceleration of Electrons by a Wave of Charge Density by Special Profiling of the Plasma Density,* soon to be published in the Lebedev Institute Journal, Fall, 1989.

16. A. Kolomensky and I. Pakhomov, *Free Electron Laser on the Basis of a Modulated Axial Magnetic Field,* Short Physics Correspondences of the USSR Academy of Sciences, 8(41), 1985.

17. A. Kolomensky and I. Pakhomov, *Collective Effects under Induced Radiation of an Electron Bunch in an Undulator with an Axial Magnetic Field,* Plasma Physics, 10, p. 1275, 1984.

18. S. Mtingwa and M. Strikman, B *Factory via Conversion of 1 TeV Electron Beams into 1 TeV Photon Beams,* Argonne National Laboratory Preprint No. ANL-HEPCP-89-96, 1989.

Ms. Angela Page
Lincoln University

Midgal-Kadanoff Study of Z_5 - Symmetric Systems with Generalized Action (I)

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Abstract

General techniques will be introduced to facilitate a discussion of the work performed by our group on Z_5 - Symmetric Systems via the Midgal-Kadanoff Real Space Renormalization Group Formalism.

Outline of Talk

I. Introduction
Background and reasons for this work

II. The Formalism

a. Properties of Z_5 - Symmetric Systems (Group Theoretical)
b. The Character Expansion and the Coupling Parameters and Expansion Coefficients
c. The Renormalization Group Equation

III. References

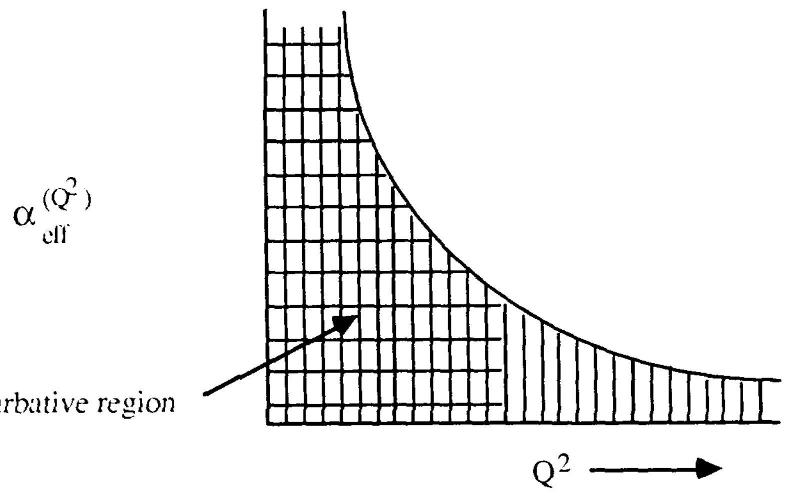
I. Introduction

Particle Physics - loosely grouped into two (2) general classifications

a. Perturbative Region

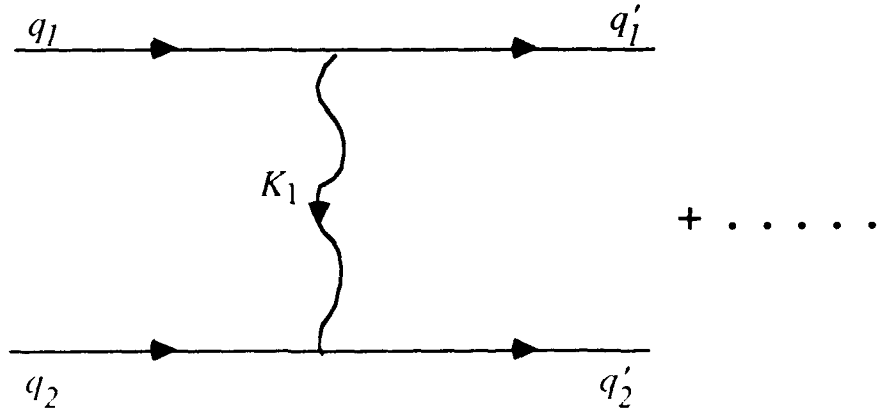
b. Non-Perturbative Region

a. For the Perturbative Region the effective coupling constant $\alpha_{eff} \to 0$ as $Q^2 \to$ large, and asymptotic freedom exists:



bottom line: as C.M. energy increases Perturbation theory can be used and one can compute scattering amplitudes & cross-sections.

For instance $q_1 + q_2 \to q_1' + q_2'$ can be computed:



The quarks in the proton or neutron act as if they are essentially free. Hence, a perturbative series expansion in $\alpha_{eff}^{(Q^2)}$ can be made.

However, it should be noted that conventional field theories develop singularities at short distances, (which correspond to large energies), and a variety of artificial techniques must be drawn upon to circumvent these infinities.

One technique is to place field theory on a lattice - ultraviolet (short distance) singularities are thus avoided.

b. **Non-perturbative Region**

$\alpha_{eff} \rightarrow 0$ so perturbative expansion is not valid and we must rely on other techniques.

Question: According to diagram I there must be a connection between the non-perturbative and perturbative regions. **Does a phase transition separate the two regions?**

Another question: Is it possible for quarks to become permanently unconfined?

These questions involve a detailed knowledge of the **Phase Structure.** Lattice Gauge Theory in conjunction with the theory of critical phenomena attempts to answer questions like these.

In this work we are examining Z_5 - Symmetric Systems to develop tools that will be useful when we try to get a handle on $Su(2), Su(3), \ldots$ . . . Symmetries. We ultimately wish to tackle the question of quark confinement.

II. The Formalism

Fixed points of the theory must be scale invariant to be physically relevant (This is because we have regulated the theory by placing it on the lattice therefore introducing fundamental length a_0, the lattice spacing, into the theory.)

Before we continue let's examine some group theoretical properties of Z_5 -Symmetric Systems:

a. Properties of Z_5 - Symmetric Systems (group theoretical)

(i) **Group Elements**

In general the group elements for Z_n - Symmetric Systems are given by [1) 2) 3) 4)]

$$\xi_{m+1} \in Z_n = e^{2\pi i\, m/n}$$

where $m = 0, 1, \ldots, n-1$

so for Z_5

$$\xi_1 = 1$$

$$\xi_2 = Cos\,\frac{2\pi}{5} + i\,Sin\,\frac{2\pi}{5}$$

$$\xi_3 = Cos\,\frac{4\pi}{5} + i\,Sin\,\frac{4\pi}{5}$$

$$\xi_4 = Cos\,\frac{6\pi}{5} + i\,Sin\,\frac{6\pi}{5}$$

$$\xi_5 = Cos\,\frac{8\pi}{5} + i\,Sin\,\frac{8\pi}{5}$$

(ii) **Coupling Constants**

The action must be real, hence for Z_n - Symmetric Systems $\beta_{n-m} = \beta_m$ (coupling constants)

b. **The Character Expansion**

ACTION

$S_\Box \equiv \sum_m \beta_m \xi^m$ and

EXPONENTIATED ACTION

$$e^{S_\Box} = e^{\beta_0 + \beta_1(\xi + \xi^4) + \beta_2(\xi^2 + \xi^3)}$$

The character expansion is defined by $e^{S_\Box} = \sum_m b_m \xi^m$ or

$$e^{\beta_0 + \beta_1(\xi + \xi^4) + \beta_2(\xi^2 + \xi^3)} = b_o + b_1(\xi + \xi^4) + b_2(\xi^2 + \xi^3)$$

where we must determine the b_i and the β_i.

c. The Renormalization Group Equation

for each β_i

$$a \frac{d}{da}\beta_i = f(\beta_i) = (d-2)\,\beta_i + 2\sum_J \frac{\partial \beta_i}{\partial b_J} b_J \ln b_J$$

Renormalization Group Equation

$f(\beta_i) \equiv$ Renormalization Group Function

Set $f(\beta_i) = 0$ to get fixed (or critical) Pts. of theory.

Preliminary Results and details for Z_5 will be given in the next talk.

III. References

1. M. Creutz and L. E. Roberts, Nuclear Physics B215 [FS7] 1983; 447.

2. L. E. Roberts, Nuclear Physics B230 [FS10] 1984; 385.

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Ms. Lavonne Carson, Lincoln University

Midgal-Kadanoff Study of Z_5 - Symmetric Systems with Generalized Action (II)

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Abstract

For Z_5 Symmetric Systems results and conclusions are given for the Midgal-Kadanoff analysis described in Part I. Work that needs to be done is also discussed.

Introduction

In this talk we will adapt the general formalism given earlier to the Z_5 - Group specifically and then we will give the preliminary results for the phase structure that we've obtained. Finally, we will discuss shortcomings of the standard Migdal-Kadanoff approach and a possible remedy.

Outline of Talk

I. Properties of Z_5 - Symmetric Systems
   a. Group Elements
   b. The Action and the Reality Condition
II. The Formalism
   a. The Exponentiated Action
   b. The Character Expansion - Details
   c. The Renormalization Group Equations
      1. for β_1
      2. for β_2
III. The Phase Structure
IV. Shortcomings
V. A Possible Remedy
VI. References

I. Properties of Z_5 - Symmetric Systems

a. Group Elements ξ_i

$\xi_1 = 1$

$\xi_2 = .3090 + .9511i$

$\xi_3 = -.8090 + .5878i$

$\xi_4 = -.8090 + .5878i$

$\xi_5 = .3090 + .9511i$

b. The Action $S_\Box(\xi)$

$S_\Box(\xi) = \beta_0 + \beta_1\,(\xi + \xi^*) + \beta_2\,(\xi^2 + \xi^{*2})$ This comes from the reality condition $S_\Box(\xi^*) = S_\Box(\xi)$ (for all $\xi \varepsilon Z_5$)

II. The Formalism

a. The Exponentiated Action

$$e^{S_\Box(\xi)} = e^{\beta_0 + \beta_1(\xi + \xi^*) + B_2(\xi^2 + \xi^{*2})}$$

b. The Character Expansion

$e^{S_\Box(\xi)} = \sum_m b_m \xi^m$ becomes

$$e^{\beta_0 + \beta_1\,(\xi + \xi^*) + \beta_2\,(\xi^2 + \xi^{*2})} = b_0 + b_1\,(\xi + \xi^*) + b_2\,(\xi^2 + \xi^{*2})$$

where

$$b_0 = 0.187\,e^{2(\beta_1 + \beta^2)} + 0.408e^{0.684\,\beta_1 - 1.532\,\beta_2} + 0.404\,e^{-1.618\,\beta_1 + 0.618\,\beta_2}$$

$$b_1 = 0.126\,e^{0.684\,\beta_1 - 1.532\,\beta_2} - 0.322e^{-1.618\,\beta_1 + 0.618\,\beta_2} + 0.196\,e^{2(\beta_1 + \beta_2)}$$

$$b_2 = 0.12\,e^{-1.618\beta_1 + 0.618\beta_2} - 0.33\,e^{0.684\beta_1 - 1.532\beta_2} + 0.21\,e^{2(\beta_1 + \beta_2)}$$

and

$$\beta_1 = 0.126\ln(b_0 + 0.684b_1 - 1.532b_2)$$
$$- 0.322\ln(b_0 - 1.618b_1 + 0.618b_2)$$
$$+ 0.196\ln(b_0 + 2b_1 + 2b_2)$$

$$\beta_2 = 0.12\ln(b_0 - 1.618b_1 + 0.618b_2)$$
$$- 0.33\ln(b_0 + 0.684b_1 - 1.532b_2)$$
$$+ 0.21\ln(b_0 + 2b_1 + 2b_2)$$

c. The Renormalization Group Equation

a. for β_1:

$$f(\beta_1) = a\frac{d}{da}\,\beta_1 = \beta 1 + (0.126\omega_1 - 0.322\omega_2 + 0.196\omega 3)b_0 \ln b_0$$

$$+ (0.086\omega_1 + 0.521\omega_2 + 0.392\omega_3)\, b_1 \ln b_1$$

$$+ (0.392\omega_3 - 0.193\omega_1 - 0.20\omega_2)\, b_2 \ln b_2$$

b. for β_2:

$$a\frac{d}{da}\beta_2 = (0.12\omega_2 - 0.33\omega_1 + 0.21\omega_2)b_0 \ln b_0$$

$$+ (0.42\omega_3 - 0.20\omega_2 - 0.226\omega_1)b_1 \ln b_1$$

$$+ (0.0742\omega_2 + 0.5056\omega_1 + 0.42\omega_3)b_2 \ln b_2$$

$$= f(\beta_2)$$

where for both equations

$$\omega_1 = \frac{1}{b_0 + 0.684b_1 - 1.532b_2}$$

$$\omega_2 = \frac{1}{b_0 - 1.618b_1 + 0.618b_2}$$

$$\omega_3 = \frac{1}{b_0 + 2(b_1 + b_2)}$$

III. The Phase Structure

Phase structure - found by finding simultaneous zeros of $f(\beta_1)$ and $f(\beta_2)$. The preliminary results are plotted below.

Note: The dotted lines are missed by our analysis but picked up by M.C. simulation.

IV. Shortcomings

- Difficulty in determining exactly where splitting occurs.

- Dotted lines are totally missed by our analysis.

V. Possible Remedy

The Roberts Formulation of the perturbative corrections to MIGDAL-KADANOFF. Hopefully it will act as a fine-toothed comb.

VI. References

1. M. Creutz and L. E. Roberts, Nuclear Physics B215 [FS7] 1983; 447.
2. L. E. Roberts, Nuclear Physics B230 [FS10] 1984; 385.
3. M. Creutz and M. Okawa, Nuclear Physics B220 [FS8] 1983; 149.
4. G. Martinelli and G. Parisi, Nuclear Physics B180 [FS2] 1981; 201.
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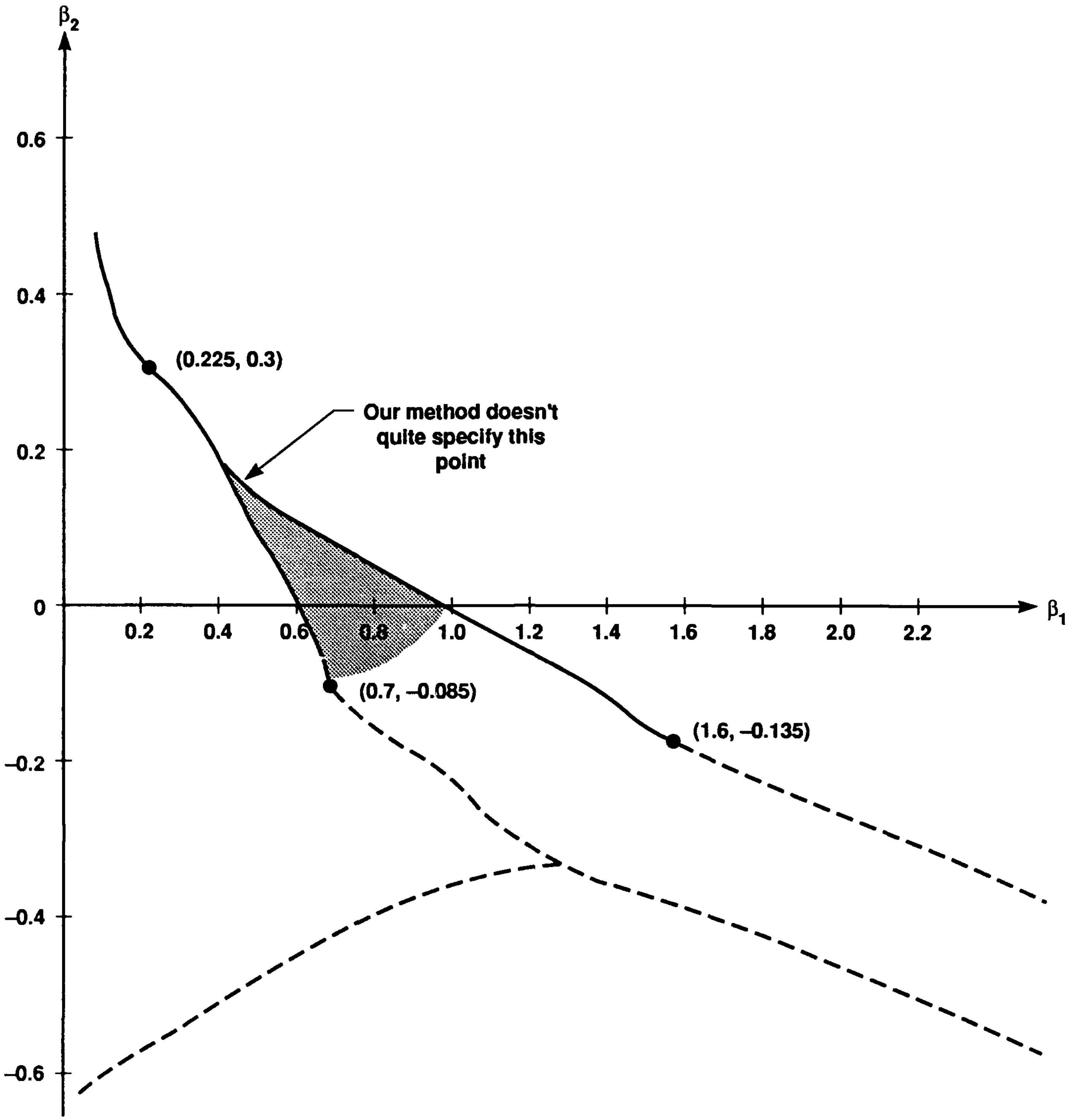
6. L. E. Roberts, Physics Letters *B* 188 (1987) 462.

This work has been funded by the U.S. National Science Foundation under grant number PHY-8715923.



β_2
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
β_1
(0.225, 0.3)
Our method doesn't quite specify this point
(0.7, -0.085)
(1.6, -0.135)

The Voyager Mission

Exploration of the Solar System with Robotic Spacecraft

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Abstract

Two spacecraft, Voyager 1 and 2, were launched in 1977. In 1989 Voyager completed reconnaissance of the Jovian planets. The mission was initially an investigation of Jupiter and Saturn; however, in-flight reprogramming allowed Voyager 2 to add Uranus and Neptune to its itinerary.

Introduction

The Voyager spacecraft have journeyed more than two billion miles in their exploration of the Solar System. For twelve years, Voyager has been extending human intelligence into space.

In 1977, the planets' relative positions were destined to be such that a Grand Tour of the Jovian Planets (the gas giants of the Solar System) could be initiated.

There are two craft, Voyager 1 and 2. Voyager 1 encountered Jupiter and Saturn, then left the plane of the ecliptic (all the planets, with the exception of Pluto, reside in a plane perpendicular to the Sun's axis of rotation). Voyager 2 also encountered Jupiter and Saturn adding Uranus and Neptune to its itinerary.

Jet Propulsion Laboratory, located in Pasadena, California, is a center of the National Aeronautics and Space Administration. It is dedicated to the exploration of the Solar System with robotic spacecraft, a precursor to human exploration and settlement. Both spacecraft were constructed at JPL, and launched from Kennedy Space Center in Florida.

The Voyager Project on-Lab is composed of Teams. The Science Team does initial analysis of the data received. Off-Lab researchers, some of whom designed specific experiments the spacecraft carries out, are sent Voyager data for analysis. The Navigation Team plotted the course, which was adjusted in-flight. The Sequence Team prepared the series of instructions radioed to the on-board computers. The Spacecraft Team drives Voyager, guiding it enroute and facilitating the encounter maneuvers.

Communication with Voyager is maintained by means of radio antennas. In order to facilitate continuous uplink/downlink, there are stations at Goldstone, California (near Death Valley); near Madrid, Spain; and at Canberra, in the Australian outback. Each station has an antenna with a 70-meter dish, as well as antennas of lesser power that can be arrayed in tandem in order to amplify the signal.

Voyager has no rocket engines; the trajectory is effected by a technique called "gravity assist": the pull of one planet propels the spacecraft toward the next.

Voyager is equipped with instruments for eleven types of astronomical investigation. At each Encounter, the spacecraft was equipped to

- determine the planet's rotation rate, temperature, weather, atmospheric composition and pressure.
- map the magnetic field.
- listen for planetary radio emissions.
- determine the size, composition, and location of rings, moons--and look for new ones.
- obtain pictures of each planetary system via two television cameras, narrow and wide angle.

Science results are radio-encoded by computers on-board the craft and beamed to Earth. Voyager carries a 20-watt transmitter, a device that has the same power as the light inside a refrigerator. It is expected that link will be maintained at least until the year 2020.

Jupiter, Saturn, Uranus, and Neptune all have a surface gas layer that extends far into their interiors. Jupiter, Saturn, and Neptune emit about twice as much heat as they receive from the Sun, Uranus 12%. They could be thought of as miniature Suns. Voyager's visits gave

ew knowledge of these planets that no ground based observations--distant, impeded by atmosphere, could provide.

Jupiter. The largest planet of the Solar System, Jupiter's volume could contain 1317 Earths. The Voyager Encounters were in March and April of 1979. Jupiter has multicolored belts, violent storms, and swirling eddies. The Great Red Spot is a storm that has been seen for the past 300 years. It rotates every six days, and would span six Earths. Jupiter's year equals 12 Earth years. Major atmospheric constituents are hydrogen, helium, and methane.

Jupiter has a strong magnetic field and emits radio noise on a broad range of frequencies. A Jovian day is less than ten hours: the rotation rate can be determined by isolating, then tracking, a single radiation source the planet emits.

There is one ring, 3200 miles wide, patrolled by two minor satellites. There are four major moons, seen in 1610 by Galileo: Callisto, Ganymede, Europa, and Io. Fifteen moons have been seen orbiting Jupiter.

Saturn. Voyager met Saturn in November of 1980, and August of 1981. The planet is readily identifiable by its many rings. Voyager found four additional rings. Saturn's rings are dynamic, changing daily. They are escorted by small moons that bind them in with interactive forces.

Saturn is essentially a monochromatic butterscotch that conceals a turbulent atmosphere. There are violent storms; Voyager clocked 1,100 mile-per-hour equatorial wind speeds. The day is about ten hours long, a year equal to thirty Earth years. The planet is twice as far from the Sun as Jupiter, and receives a quarter as much light. Major constituent elements are hydrogen, helium, ammonia, and methane. Saturn has a magnetosphere.

There are eight major satellites. Titan is the largest moon of the Saturnian System, and the first in the Solar System encountered that has an atmosphere. Twenty satellites have been seen around Saturn, many carrying water ice.

After Saturn, Voyager 1 rose above the ecliptic to search for the upper limits of the Solar System, the place where the Solar Wind dissipates.

Eight years into its journey, Voyager 2 arrived at Uranus. Data transmission time was two hours and forty-five minutes. The planets are not evenly spaced in orbit radius; each one is further from its predecessor than the distance between the pair before. Low light levels and speed of passage necessitated the development of techniques that would prevent image smearing in the cameras with extended exposure time. Three methods of Image Motion Compensation were developed:

1) Classical IMC--The spacecraft turns such that the camera tracks the target. The image is recorded on the on-board digital tape recorder. During this maneuver, the spacecraft breaks communication with Earth.

2) Nodding IMC--The spacecraft is "nodded" off Earth-point, the frame is shuttered, and Earth-point attitude reacquired. The entire maneuver is 17 seconds in duration, and repeated. This technique was used when close-encounter high data rates would have filled the tape recorder, with no time available for downlink.

3) Maneuverless IMC--The Scan Platform (on which the cameras reside) movable in azimuth and elevation, tracks the target.

These techniques allowed Voyager to handle exposures of up to one minute, and obtain images while moving at high speed. The launch software programs were written to handle 15-second exposures.

Uranus. The third largest planet was encountered in January of 1986. It lies on its side, i.e., its axis is nearly co-parallel with the ecliptic. The unusual orientation is thought to be the result of a collision with another body--a body whose debris now encircle the planet in the form of eleven rings and some of the moons.

The Uranian year equals 84 Earth years. Uranus is 1,767,000,000 miles away. A day is about seventeen hours long.

Voyager's close-up view shows that Uranus is a glowing blue-green. Neutral hydrogen encases the planet. When sunlight strikes neutral hydrogen, it glows. Methane, a major component of this atmosphere, is blue-green. Helium has also been detected.

Uranus' magnetic field is tilted 60° from its rotational axis. Other planetary magnetic fields were found to be co-parallel to the rotational axis.

The eleven rings are dark, unlike Saturn's. Voyager discovered two of them. There are fifteen satellites, ten discovered by Voyager. Miranda, 293 miles in diameter, has a surface so geologically diverse it is thought to be composed of extremely large blocks randomly aggregated--a reconstituted moon.

Neptune. Voyager made its last scheduled encounter in August of 1989. It passed a close 2700 miles over the north pole of Neptune, travelling at 61,148 miles per hour. Little had been known about this planet, it cannot be seen without a telescope, and receives one thousand times less sunlight than the Earth does. Major planetary constituents are hydrogen, helium, and methane, as with Uranus. Neptune is about the same size as Uranus, rotates at about the same great speed, and has a magnetic field. One of Neptune's years is equal in length to 165 Earth years.

Jupiter has a Great Red Spot; Neptune has the Great Dark Spot. Cirrus clouds were plainly seen in the blue planet's atmosphere. Five rings were visible to the spacecraft.

Triton and Nereid, the planet's known moons before Encounter, were imaged. Nereid seems to be a nonspherical fragment. Triton has an atmosphere and a magnetic field, leading observers to suspect that it is a minor planet captured by Neptune's gravity. Voyager discovered six additional moons.

Perturbations in the orbit of Neptune have been detected. An Earth-sized planet could be the cause. Irregularities in Uranus' orbit, led to the calculation of Neptune's orbit and location in 1845; it was discovered a year later. Disturbances in Voyager's expected cruise trajectory would indicate where to look for Planet X.

Voyager 1 and 2 will give us their astronomical observations, look for the limits of the Solar System, and perhaps indicate the presence (or the absence) of Planet X until they can no longer be tracked. It is expected they will reach Solar System Edge before the turn of the century.

The Mission continues. Robotic spacecraft continue investigation as a precursor to human exploration of the planets.

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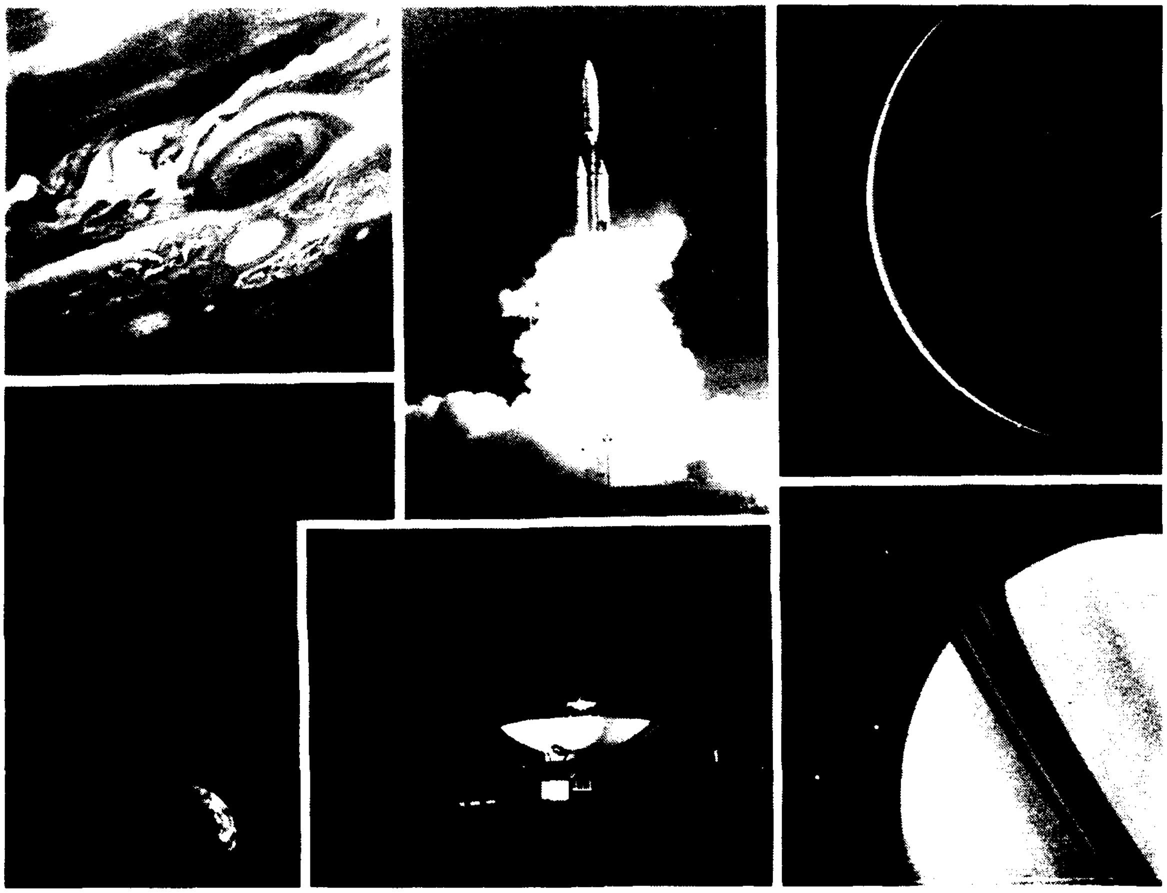

Fig. 1 Clockwise from left,: The planet Jupiter, as seen by Voyager 2; Voyager is launched in a Titan-Centaur rocket from Kennedy Space Center, 1977; Voyager 2 image of the planet Uranus; image of the planet Saturn, Voyager 1; the Voyager Spacecraft; the Earth and the Moon as seen by Voyager 1, 1977.

Fig. 2 Voyager 2 image of the planet Neptune.

Dr. Julian Earls
NASA Lewis Research Center

Professor Francis Allotey, University of Science and Technology, Kamasi, Ghana (seated); and Professor Joseph Johnson, CUNY (standing)

Banquet Address

Francis K.A. Allotey

University of Science and Technology
Kamasi, Ghana
West Africa

Mr. President, distinguished guests, fellow scientists, ladies and gentlemen, I deem it a great honour and pleasant duty to talk to you today and to participate in your annual general meeting. Firstly, I wish to convey to you warm and fraternal felicitations from Africa. Secondly, my heartfelt thanks go to Prof. J. A. Johnson III., President and Dr. Kennedy Reed, President-elect of the National Society of Black Physicists who have made my trip to this conference possible. Thirdly, I wish to assure you that we are looking forward to welcoming you this August in Accra, Ghana, where W. E. DuBois is buried for the Second Bochet Conference. You will receive the proverbial Ghanaian hospitality.

My discourse will consist essentially of three parts I shall give a brief bird's eye view of the current state of science and technology in Africa then, talk about the Society of African Physicists and Mathematicians (SAPAM) of which I am founding president and lastly but not the least, about the needed and exigent cooperation between Black American physicists and African scientists for the socio-economic development of Africa, where you and I have common roots. We who are living there now are only holding the fort in trust for all people of African descent including the diaspora.

Africa is a vast continent and is the second largest. It covers an area of approximately 11.7 million square miles and 18 inhabited by about half a billion people, that is about one tenth of the total world population (1988). It is made up of over 50 sovereign states with diverse cultures. It has about 850 distinct languages (not dialects) of the total world languages of 2,000, that is, Africa alone possesses 40% of the world languages. Ghana with a population of 14 million has 44 languages. Nigeria with a population of 100 million has over 200.

In our contemporary society, science and technology hold the master key to social and economic development of the third world nations. The "South Korea Miracle" is a vivid example; science and high technology have brought the Green revolution in agriculture, dramatic reductions in diseases and mortality rates. We are all witnesses of advances and

spin-offs from the space technology which have led to village television and inexpensive rural telecommunication networks. In fact, a nation's development plan (industrialized or developing) can hardly be conceived and implemented without the massive integration of science and technology into it. But science and technology, however, have contributed less to economic and social development in Africa than any major region of the world.

For instance, according to the 1986 UNESCO statistical year book, of the 3.7 million research and development scientists and engineers (RDSB) in *the* world just over 10% work in developing countries as a *whole* with only 0.4% in Africa, 0.9% in Arab countries and 2.4% in Latin America. In more graphic terms while the number of RDSE in the third world per million of population is 125, in Africa it is only 52, in Latin America 287 and in Asia 284.

The problem is even more acute and depressing in the relatively new area of high technology. If we consider, for example, informatics, according to a 1983 survey by International Data Corporation, Africa is the least informatized region. Africa's share of the world expenditure on information technology is barely 0.3% as against 95% of the industrialized countries.

The need therefore to greatly increase expenditure on science and technology in Africa cannot be over stressed. Africa's backwardness in science and technology could be traced to its colonial past.

Historically, the study of science and in particular physics in Africa excluding South Africa is recent; as a consequence African scientists have a rather low level of scientific and technological tradition from which to make an impact.

Up to 1950 there were only twelve universities in the whole of Africa including South Africa. A serious study of physics for example in West Africa began only after the establishment of the University of Ibadan in Nigeria and University of Ghana, both in 1948.

African countries have not been indifferent to the need to open more universities to educate people in science and technology. The universities in East, Southern and Central Africa including those in most Francophone countries were founded in the late fifties and sixties

just before or after those countries gained sovereignty. Now there are more than 100 universities in Africa. Nigeria alone has over 30 universities.

It is worth observing that the majority of people trained in Africa, in Europe and in the US before their countries gained independence did study professions needed to run and serve the colonial administration. For example, the University of Sierra Leone was founded in 1826 (as Fourah Bay College) in Freetown to educate and train colonial administrators for the whole of British West Africa (the Gambia, Sierra Leone, the Gold Coast and Nigeria). It did produce its first graduate physicist only in 1973. This is to show what low priority was given to the study of science and technology in the colonial days in Africa.

Physics and Mathematics form the basis of most of the basic sciences and technology and thus for Africa to participate in the ongoing scientific and technological revolution on which our contemporary society is based and organized, it is very essential that these subjects are given high priority in educational programs in African schools and universities.

African scientists and leaders are not unconcerned about this poor state of affairs. It is a little wonder therefore that on the 26th of August, 1983, 34 physicists and mathematicians from 20 different African Countries then visiting the International Center for Theoretical Physics (ICTP), in Trieste, Italy, met to consider the numerous problems affecting physics and mathematics in particular and science in general in the continent of Africa.

Prominent among these problems were: the declining standards of teaching in physics and mathematics at the secondary and tertiary levels in Africa, the poor level of research in these subjects at the universities and higher institutions, the apparent lack of cohesive and functional links among researchers in these fields in Africa, the absence of any adequately funded and well equipped home or center of excellence for research and learning in physics and mathematics. It was recognized that the technological gap between the advanced North and the poorer South was nothing else but a clear manifestation of the state of science and technology in the South and that this gap would continue to widen as long as physics and mathematics, the bedrock of modern technology and other science, continue to be neglected. As a result of these deliberations, the Society of African Physicists and Mathematicians was born. Here great thanks should be given to Prof. A. Salam, Nobel laureat, great visionist and our chief patron for his continuous support and encouragement. Professor Salam is also the brain behind the Bouchet-ICTP Institute. SAPAM has over

600 members from over 30 African countries. The society is open to every African physicist and mathematician working in Africa.

The aims and objectives of SAPAM are:

(a) To promote and further education and research in physics and mathematics and their applications in order to enhance technological, economic, social and cultural development in Africa.

(b) To promote effective contacts and cooperation among African physicists and mathematicians.

(c) To collaborate with national and international organizations with similar objectives in furthering scientific and technological activities in Africa.

Within the first year of the Society, it was able to organize successfully a symposium on "The State of Physics and Mathematics in Africa" in Triest, Italy, from 16-18 October, 1984. It is worth mentioning that the first Bouchet Conference also took place in Triest from 9-11 June 1988, that is barely four years after the founding in SAPAM.

The symposium was aimed at creating a forum for a large representative community of experiences African physicists and mathematicians to study and recommend solutions to numerous problems affecting physics and mathematics education in Africa and to promote cooperation among them. It was a Pan African meeting with over 100 participants from 30 African countries.

In 1986 another Pan African workshop on curriculum development and design in physics and mathematics and computer science at the tertiary level was held in Nairobi, Kenya. Here too, it was very successful and there were over 125 participants from 35 African countries. Proceedings of our 1984 and 1986 Pan African activities have been published.

In 1987 and 1989 SAPAM organized very successfully Pan African College in Addis Ababa, Ethiopia on "Applicability of Environmental Physics and Meteorology in Africa". The Society has also organized several smaller workshops/conferences/symposia on subregional level in Africa. Prominent among them may be mentioned "Abidjan International Symposium of Mathematicians" series. It takes place biennially in Adidjan,

Cote D'Ivoire. "Kumasi International College on Energy" series which takes place every other year in Kumasi, Ghana.

The first International Workshop in Africa on medical physics was held in Accra, Ghana in July last year. A conference on Advances in Communication Physics was held in Ilorin, Nigeria, 1989.

Many other activities are planned for the future such as a "college on teaching physics, mathematics and computer science at tertiary level" in Accra, Ghana, a Photo voltaics conference in Lagos, Nigeria and conference on desertification in Cairo, Egypt.

These activities have been made possible with generous support from ICTP and also from donor agencies such as Swedish Agency for Research Cooperation in Developing Countries (SAREC), OPEC Fund, UNESCO and WMO.

Mr. President, ladies and gentlemen, it must be emphasized here that buying technology without the ability to study them, maintain them efficiently and above all to learn how they work with a view to being able to improve on them by our experience can delude us after some time.

In fact one can pay for equipment and services but one does not buy technology. To be owner, technology must first be mastered, locally produced and totally integrated into the society, culture and environment of the people. Presently Africa is buying technology without owning it. We need your assistance to reverse this trend.

For industrialization to germinate and blossom in Africa, physics and mathematic- must be integrated fully into its educational programme since these subjects form the basis of modern technology.

In saying this, I am not unaware that some people in higher places question the need in spending scarce financial resources of Africa on physics and mathematics teaching and research. They argue that what Africa needs is people who can cure the sick, people who till the land and people who can construct buildings, bridges and roads. These people fail to comprehend that science and technology are the baseline on which the green revolution in agriculture, modern medical practices and the construction industry lean.

As I have said before, science and technology constitute an integral part of tho culture and heritage of the modern person and for these reasons the people of Africa cannot be left out of the mainstream of this culture and heritage on which our contemporary civilization is founded.

There are others who argue against investment in research and education in basic science in general. They fail to recognize that what is basic science today could be technology tomorrow. It is no wonder therefore that the 1983 report by National Academy of Sciences, National Academy of Engineering and the Institute of Medicine in USA on the "Frontier in Science and Technology" has this to say on basic science: "More than ever, basic science will be vital to technological advance and in turn to better productivity and enhance economic growth". In the same report, it was emphasized that the traditional disciplinary boundaries are dissolving between fields of basic sciences and between the basic science and technology. As example of this trend they consider how solid state physics has merged with material sciences and chemical engineering and computer science to produce new catalysts and micro-electronic fabrication methods; how optics, solid state physics and cellular biology have merged in the creation of flow cytometry for analysis of coll components; how robotics and phychobiology merge in their analysis of vision.

Fundamental studies of how a smoothly flowing fluid becomes a turbulent one, devolves into mathematics, in physiology, in dynamics of tho atmosphere and galactic structure etc. etc.

In his selected essays "Physics in 20th Century", Prof. V.F. Weisskopf gave interesting illustrative examples of how decisive technical progress was made by physicists who did not work at all for a well defined practical aim.

Here I quote three:

(a) One might ask whether an electronic industry could exist without the previous discovery of electrons by people like J. J. Thompson and H. A. Lorentz. It did not happen that way.

(b) Whether in an urge to provide better communication one might have found electromagnetic waves. They were not found that way. They were found by Hertz

who emphasized the beauty of physics and who based his work on the mathematical considerations of Clerk Maxwell.

(c) One might ask whether basic circuits in computers might have been found who wanted to build computers. As it happened, they were discovered in the 1930's by physicists dealing with counting of nuclear particles.

Mr. President, distinguished guests, ladies and gentlemen, basically problems and difficulties facing Africa in initiating and sustaining physics, mathematics and other science and technological programs for industrialization are threefold: trained manpower, lack of financial resources, and working in isolation.

Africa has produced first class administrators, lawyers and the clergy but fewer scientists and engineers.

Physics research is very expensive. Gone are the days when Nobel Prize winning experiments could be performed in an attic of a university building using wax, pieces of wire, thin films, galvanometers etc., etc. Most countries in Africa are currently fighting problems brought about by drought, high fuel and falling commodity prices. Take as a concrete example, in the mid 70's to import into Ghana a tractor, we needed to export two tons of our cocoa. In February 1990 to import a similar tractor we have to export eighteen tons. What I am trying to draw your attention to here is that the poor economic predicament of Africa is not entirely of Africa's own making but the result of the unjust international economic order we find ourselves in a s a consequence of our colonial past.

Foreign exchange is very hard to come by for African governments to allocate a meaningful amount of it to scientific equipment, journals and books.

An African scientist more often than not is isolated, working and researching alone. He lacks the needed foreign exchange to enable him or her to make contact outside his or her locality. He may spend months working on a certain problem just to find out later that the problem had been solved long ago.

How do we solve these problems? We in Africa believe that our brothers and sisters African Americans here in the USA can help. Here I am reminded of the bold and great statement of Osagyefo Dr. Kwame Nkrumah, the first President of the Republic of Ghana

at the time Ghana gained her independence - incidentally Ghana was the first black African country to be independent. He said and here I quote, "The independence of Ghana is meaningless unless it is linked with the total liberation of the whole of Africa".
One of the greatest black leaders of this century who had the most influence on Nkrumah was Marcus Garvey. The Great Marcus Garvey's solution many years ago to the same problem was that people of African descent should go back to Africa, settle and help to restore Africa to its great and glorious past.

Mr. President, this physical movement is no longer necessary. Thanks to modern, fast and efficient communication by air transportation and telecommunication, you can assist Africa from your base here in North America, this is the moving spirit and force behind Bouchet-ICTP Institute. I salute the founders of this Institute for their great vision, for among its aims and objectives are to provide African physicists and black American physicists with a forum to:

- share their research results;
- discuss current topical issues in physics, mathematics and fundamental sciences;
- give rise to mutually beneficial collaboration and continuing relationships.

We have to work hard to make the Institute a success. There is a need for a Science Foundation in the USA to aid Science and Technology Research and Development in Africa to support the Institute and SAPAM. I hope there will be generous contribution from all African Americans and others.

Mr. President, It is a truism that the present developing countries are those countries that missed the Industrial revolution about two hundred years ago. It 18 almost certain that the least developed countries of tomorrow will be those countries which will miss the ongoing scientific and technological revolution.

Africa cannot afford to be left behind again. This will happen if you do not assist us to help ourselves in science and technology. If this happens and I sincerely hope not, your great grandchild yet unborn will point an accusing finger and ask: what did great great granddaddy do when he could have contributed a widow's mite?

Thank you.

LEFT to RIGHT: Dr. Walter Lowe, AT&T Bell Laboratories; Dr. Deborah Jackson, GEM Program; Professor J. D. Garcia, University of Arizona; Ms. Nan Snow, National Physical Science Consortium; Dr. Benjamin Zeidman, Argonne National Laboratory

Graduate School: A Gateway to Opportunity

L. Nan Snow

Executive Director
National Physical Science Consortium

Students, you are in the right place at the right time! This is a time of tremendous challenges and opportunities.

We know that by the year 2000 there will be a cumulative shortfall of 430,000 BA degrees in science and engineering and a cumulative shortfall of 8000 Ph.D.s.

This problem is exacerbated by a number of conditions that prove to be challenges that we as a nation will have to address more effectively. These challenges are:

1. Most K-12 teachers don't understand the difference between reading about science and doing science.

2. The average K-6 school has $300/year for science materials.

3. Our K-6 science programs are the same as those found in the third world.

4. In 1983 we decided we would have a layer cake science education in this country.

5. We are the only western country that does not take into account the effectiveness of utilizing the spacing effect in science education. (Spreading a subject out over three years increases learning.)

6. In 1986 there were 23,000 high schools in the US; 7100 of these schools had no physics courses, 4200 had no chemistry and 1900 schools had no biology. Also, only 39% of these high schools offered laboratory courses in science.

7. In a recent 1989 international survey of high school seniors of 13 countries, the US ranked 13th in biology, 11th in chemistry and 9th in physics.

In the light of these existing conditions, I want to congratulate each and every one of you students for having survived in one of the bleakest educational pipelines in the western world.

Now let us look at the opportunities. Between now and the year 2000 there will be:

1. A continuing high demand for physicists by both industry and government. It is projected that there will be 6500 new jobs by the year 2000 plus an 18% increase in existing areas.

2. An aging faculty will continue to retire, providing numerous opportunities for an academic career. In 1987, 316 academic vacancies had been open for two or more years. In 1989, average academic salaries offered ranged from $50-$57K/year. Additional laboratory setup packages have moved from $20K to $250K plus signing bonuses. In 1989 the highest laboratory setup offer was $780,000.

You have the opportunity to be a leader in science! At the Ph.D. level you are able to not just do science, but to <u>create</u> and <u>make</u> science.

If you want the comfortable life style, the interesting research, the excitement of intellectual challenge, then go for your Ph.D. It will be a difficult challenge, but it will be worth it, and you can do it.

To succeed if you want to do something different you must indeed <u>do</u> something different. Become focused on your goal. If sacrifice is required to get those grades, then commit to that goal the energy to do what is necessary to make those grades.

Talk to people who are successful in the areas you wish to work in. Find out how they got to where they are and find out what you can learn from them. Role models and mentors are important! Find one for yourself and be one for another.

Find out which are the best schools in your field, check out what the admission requirements are and apply in a timely fashion to at least three to six of these universities. Be clear in your statement of interest. Make sure you type your applications and fill them out completely. Messy, unclear or incomplete applications may cause delays in your admission.

When you ask your professors to write a recommendation for you to a graduate admissions office or for a fellowship, make sure you ask each one of them if they can give you a good recommendation. It may be painful, but it is best to know up front. If one of them says "no," then thank them and go find a professor who says "yes." It is the positive recommendations with specific examples that illustrate your performance and research capability that are of most interest to the reviewers of your application.

Study for your GRE's and take your GRE's early! The best time is the last of your junior year. This will give you the opportunity to take them again in October of your senior year if you are dissatisfied with the scores. The absolute drop dead date to take these exams is October of your senior year. In order to qualify for numerous fellowships, your GRE scores must be available by the first of December.

Apply to a number of fellowship programs. The program I represent is offered by the National Physical Science Consortium. We offer a six year fellowship that is worth $150,000 to $180,000.

The unique features of the National Physical Science Consortium fellowship are:

- Paid tuition and fees plus a substantial stipend for each academic year at nationally recognized universities through the U.S.

- Paid summer employment and technical experience for at least two (2) years from leading national employers in the U.S.

- Mentors on campus and at the work site.

- A long-term commitment to each qualifying fellow for up to six (6) years.

- Opportunity to present cameos of your research at national meetings.

- Build networking with leading scientists from both major research laboratories and universities.

You may be eligible for a fellowship if you:

- Are a U.S. citizen;
- Are Black, Hispanic, Native American and/or female;
- Have an undergraduate academic standing as a senior with at least a 3.0 GPA;
- Are an entering or returning student.

Your fellowship is worth from $150,000 up to $180,000. NPSC fellowships pay tuition, fees and a stipend for each graduate year, plus you earn money through the summer employment program. The initial stipend for years 1 and 2 is $10,000 plus full tuition. Stipend for years 3 and 4 is $12,500/year and years 5 and 6 is $15,000/year. The exact value depends on your academic standing, summer employer and graduate school. A list of member employers and universities is attached.

Applications are available at the graduate offices of your college or university, or at the address below.

L. Nan Snow, Executive Director
National Physical Science Consortium
Headquarters Office
University of California, San Diego D-016
9500 Gilman Drive
La Jolla, CA 92093-0016
Phone: (619) 534-7183/7327
FAX: (619) 534-7379

Applications are due December 1, 1990 for the NPSC 1991 awards, so write early for your application.

Your completed application will be reviewed by the University Screening Committee on December 17, 1990 and awards will be made by the Selection Committee on January 21, 1991.

If you would like further information about the program, call me at (619) 534-7183 or write and request an application package.

Remember, graduate school is free. So set yourself free. Push your boundaries. Set your sights high. Spread your wings and soar!

SIGNATORY INSTITUTIONS TO THE NATIONAL PHYSICAL SCIENCE CONSORTIUM

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University of Oregon
University of Rochester
University of Texas at Austin
University of Texas, El Paso
University of Virginia
University of Wisconsin, Madison
Washington University, St. Louis
West Virginia University, Morgantown
Yale University

Change, Challenge and Opportunities

Manual Perry

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Abstract

"Change, Challenge and Opportunities" is a presentation which describes the dynamic new environment into which organizations are quickly entering. Major technological shifts are occurring; social behavior is changing; political activism is increasing; and economic uncertainty prevails.

If national changes are not enough, organizations must begin anticipating regional changes due to growth and development. Organizations will be affected by, or will be involved significantly in, the relocation strategies of major corporations, transportation plans of cities, and regional discussions of local development. Workers must anticipate the change in work and prepare for tomorrow's careers. Work of tomorrow will not be what we do today.

We will use graphs and supporting documentation to identify trends and their implications, and to provide focus for determining the major planning challenges of the 80's and 90's. Issues impacting the region between now and the year 2000 will be presented.

Strategic Human Resource Opportunity

Manuel Perry

Manager, Human Resources, Planning and Development

Lawrence Livermore National Laboratory

Changes in the needs of business

- **Need to fill new jobs**
- Need for competent workers
- Need for workers with updated skills/knowledge

Changes in the needs of business

- Need to fill new jobs
- **Need for competent workers**
- Need for workers with updated skills/knowledge

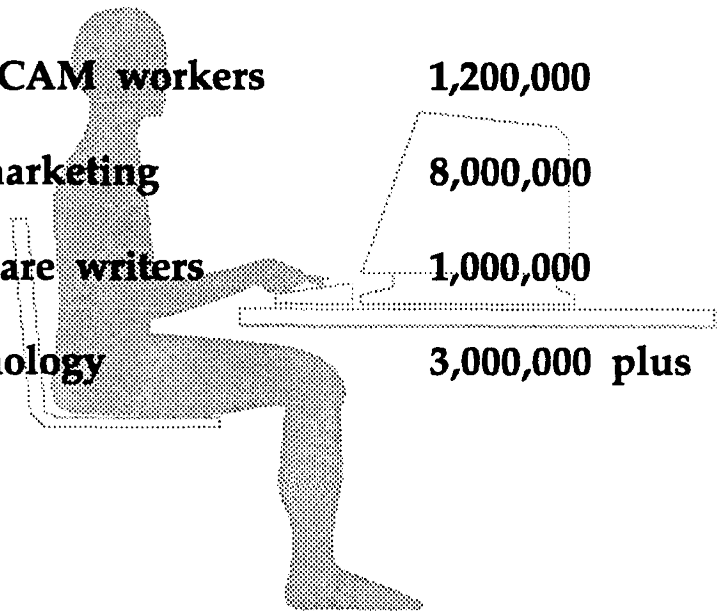
Changes in the needs of business

- Need to fill new jobs
- Need for competent workers
- **Need for workers with updated skills/knowledge**

Fastest growing job areas are:

- Medical Services
- Business Services
- Computer Services
- Peripheral Equipment
- Material Handling
- Transportation Services
- Professional Services

New jobs by the year 2000



CAD/CAM workers	1,200,000
Telemarketing	8,000,000
Software writers	1,000,000
Technology	3,000,000 plus

Fastest growing job types are:

- Computer programmers
- Medical assistants
- Electronic engineers
- Physical therapists
- Lawyers

Companies involved in special education

Dow Chemical	Xerox
Prudential Insurance	Pizza Hut
American Express	Metropolitian
Coca Cola	Boston Compact BW

Tomorrow's job's will require more education

Years of schooling needed for job	Current jobs	Future jobs
8 years or less	6.0%	4.0%
1–3 years of high school	12.0	10.0
4 years of high school	40.0	35.0
1–3 years of college	20.0	22.0
4 or more years of college	22.0	30.0
Median years of school	12.8	13.5

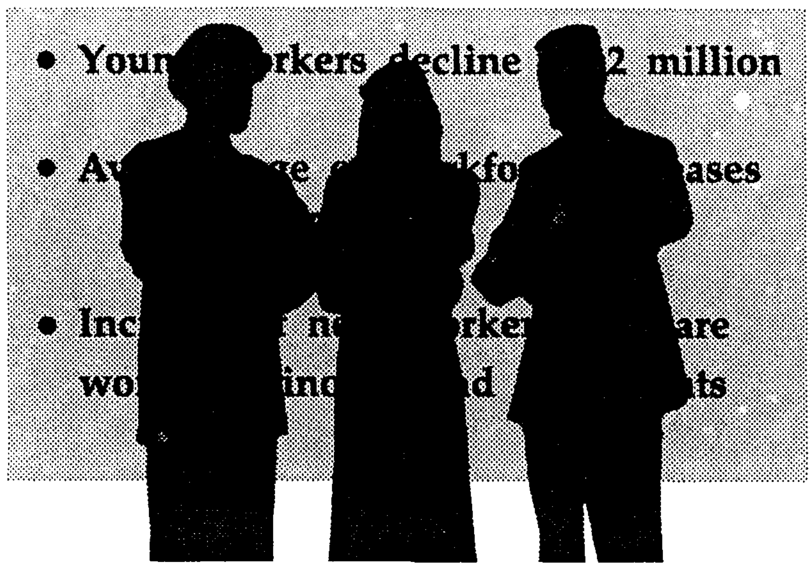
(For new jobs created between now and 2000)

Data: Hudson Institute, BW

Changes in work and the workforce

- Work is changing
- Work skills are changing
- Worker utilization is changing
- Worker demographics are changing
- Worker participation is changing

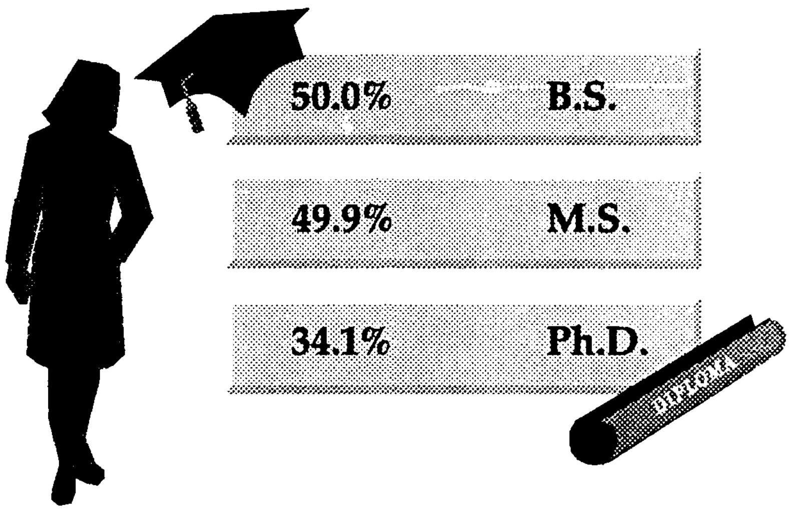
Demographics are changing



Changes in education institutions

- Graduates from schools are changing
- Discipline enrollments of U.S. students are changing
- Number of students going to college is changing
- Educational institutions are changing
- Educational curricula are changing
- College faculties are changing
- Academic quality is changing

Women percent of total all degrees granted has changed



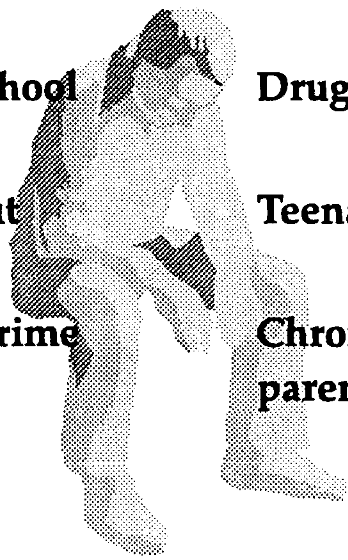
Percent minorities receiving degrees in computer science

B.S.		M.S.	
Indian	0.4%	Indian	0.6%
Black	5.5%	Black	2.5%
Hispanic	2.1%	Hispanic	1.3%
Asian	5.2%	Asian	8.3%

Students going to college changing

- 18% drop in college age kids
- 700,000 students drop out of schools
- 500,000 are barely literate
- 13% of 17–year olds are functional illiterates

Thirty–three percent of school age kids are at risk



Failing at school

Dropping out

Victims of crime

Drugs

Teenage pregnancy

Chronic unemployed parents

High school graduates eligible for U.C. system

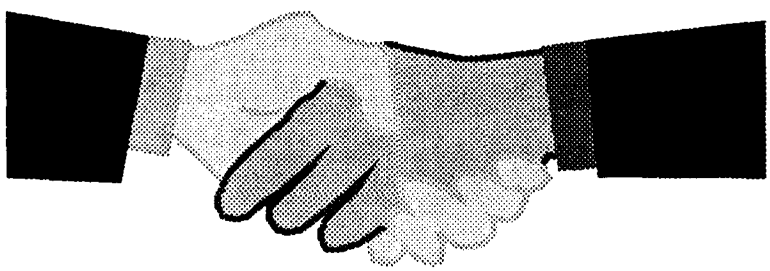
Asian graduates	26%
Anglo	13%
Hispanic	4.5%
Blacks	3.6%

Organizational implications

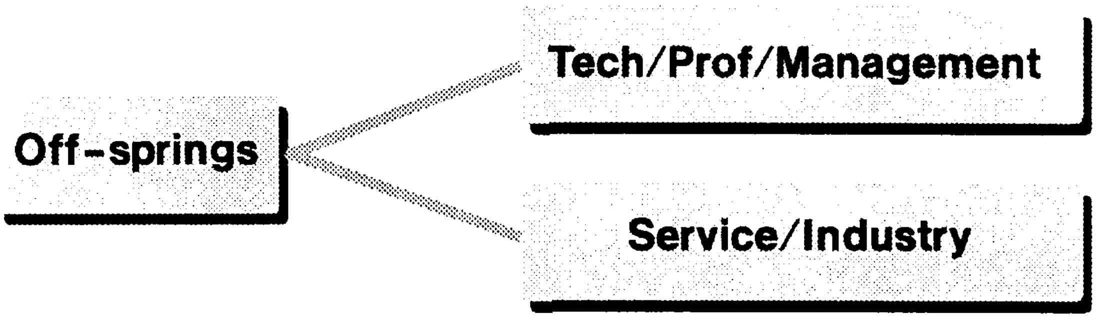
- Need to be acutely aware that the labor force and the workplace will be different in the future
- Need to be able to respond to labor markets that will tighten more than any time in history
- Have to invest in training and retraining of their existing employees
- Must develop strategies to insure an on-going, constant supply of new talent from educational institutions

Strategic Human Resource Opportunity

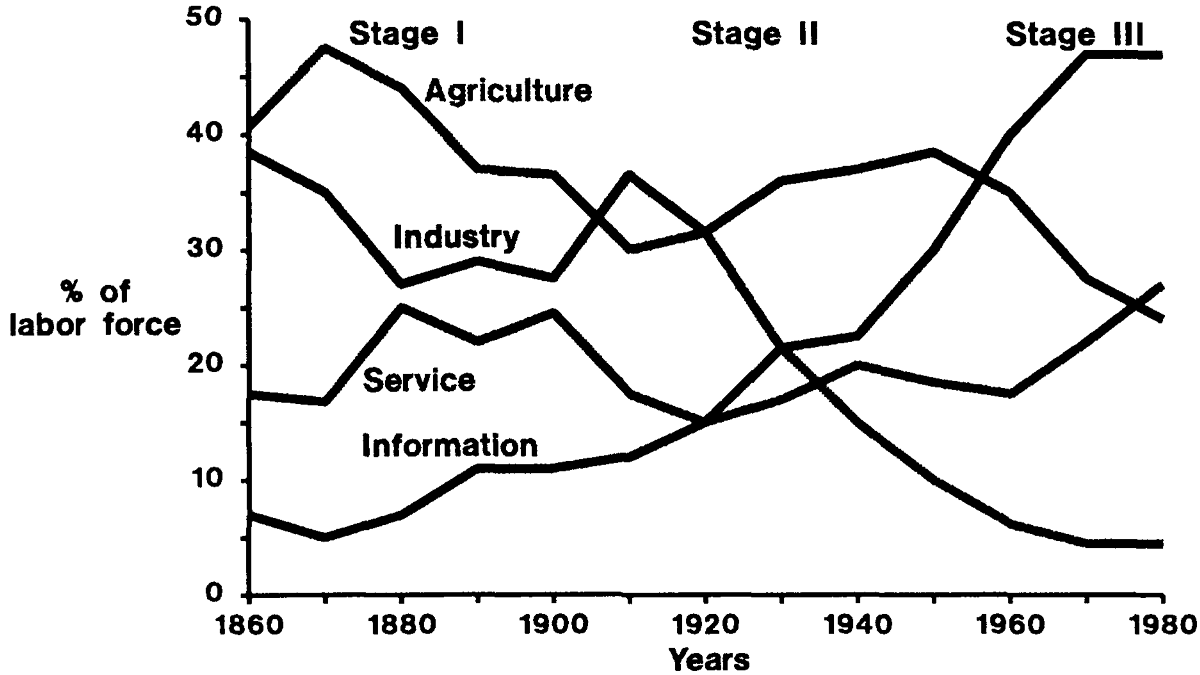
Organizations need to develop a well – planned well – orchestrated approach to establish strong institutional relationships with key educational institutions



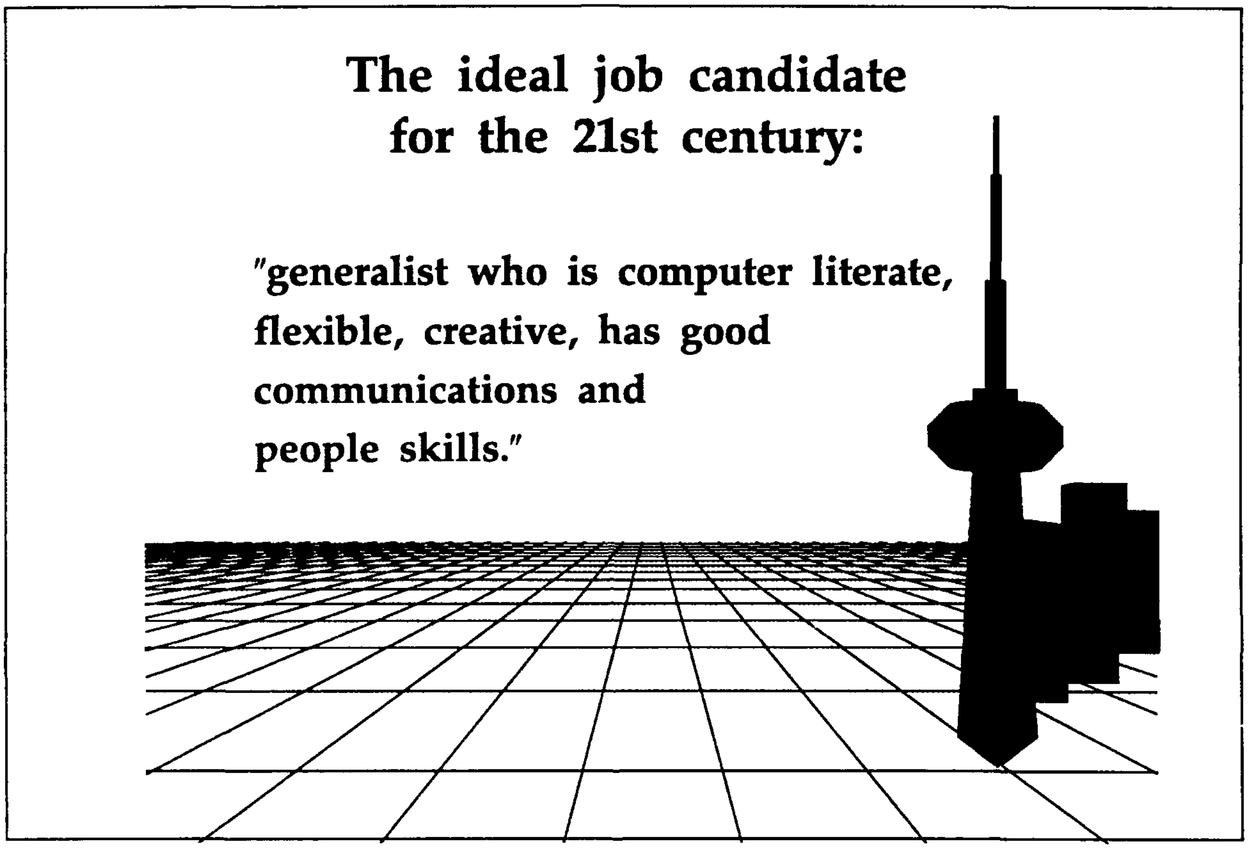
Fewer jobs for Middle – class off – springs



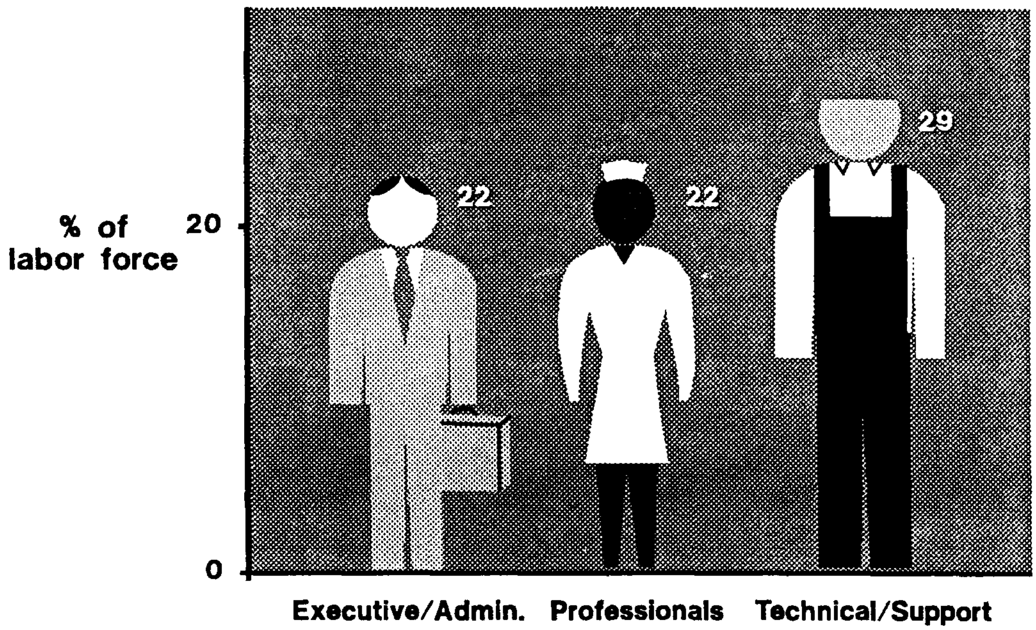
Shift to the Post–Industrial era is already well in progress



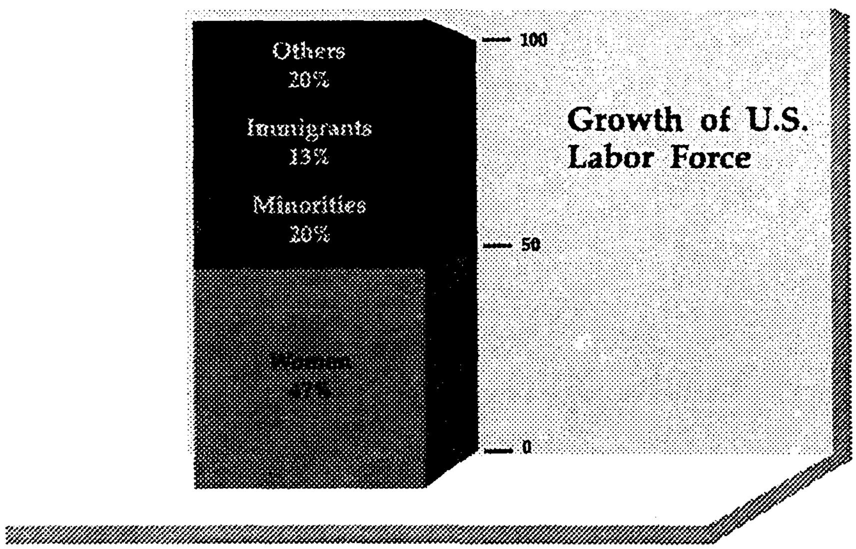
Source: Daniel Bell, Harvard Univ.


The ideal job candidate
for the 21st century:
"generalist who is computer literate,
flexible, creative, has good
communications and
people skills."

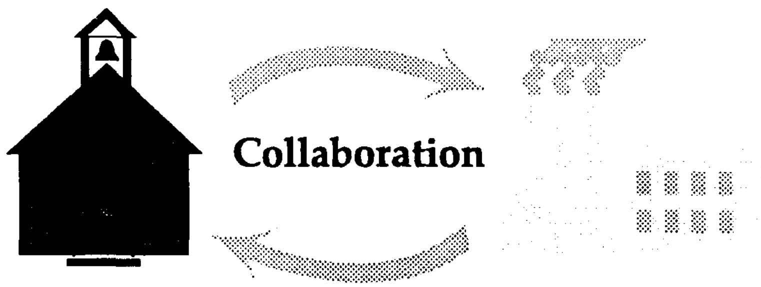
Work Skills are changing 1984 – 1995



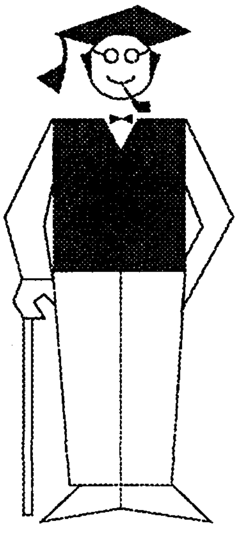
Worker utilization is changing



Educational institutions are changing



College faculties are changing



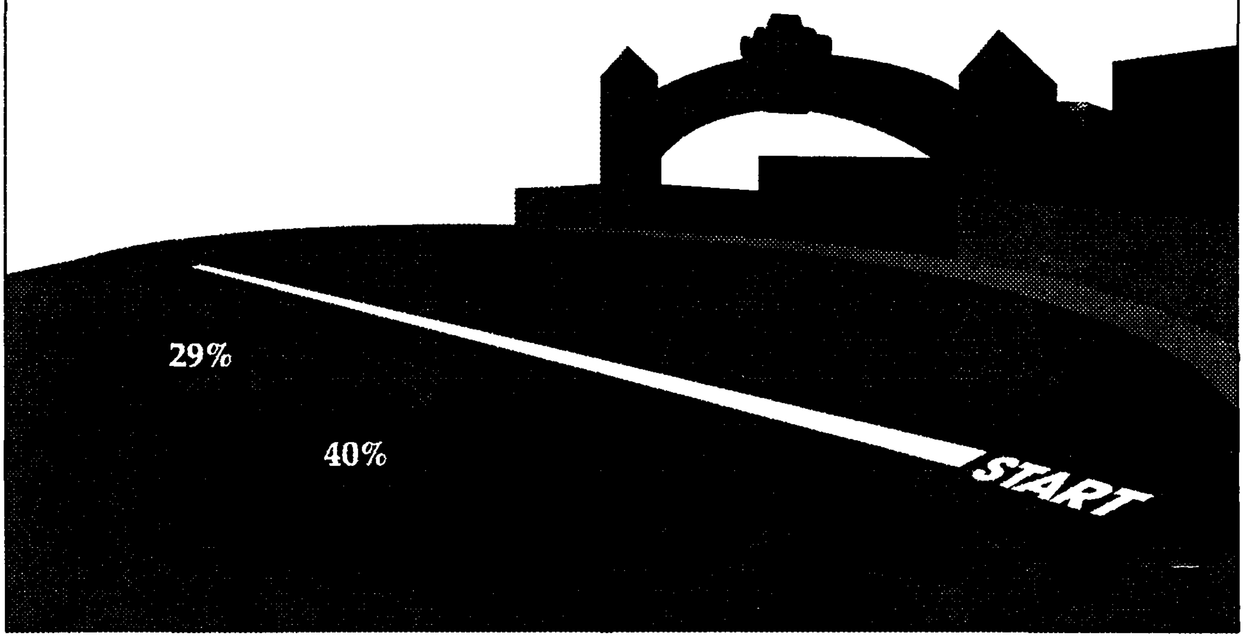
Nation – wide
500,000 hires
by 2000

Educational curricula are changing

"Educational institutions must restructure their programs, redesign labs and retrain faculty. Business, industry and the community will directly benefit and their involvement must increase."

— Dialog

Student academic quality is changing



13th ANNUAL MEETING
NATIONAL SOCIETY OF BLACK PHYSICISTS

PROGRAM

WEDNESDAY, MARCH 21

6:00 - 9:00 p.m.		Conference Registration - Bellemont Hotel Reception and Hors d'oeuvres Sponsored by Lawrence Livermore National Laboratory

THURSDAY, MARCH 22

9:00 a.m.		**MEMORIAL SESSION for Dr. Ernest Coleman**
	Speakers:	Professor Homer Neal Mr. Al Ashley Mr. Charles Jones
		OPENING SESSION
	Presiding:	Dr. Diola Bagayoko Department of Physics Southern University
	Welcome:	Dr. Dolores R. Spikes, President Southern University System & Chancellor Southern University
		Mr. James Evans Assistant Associate Director Lawrence Livermore National Laboratory
9:45 a.m.		**SCIENTIFIC SESSION I**
		Dr. Shirely Jackson AT&T Bell Laboratory *Optical Properties of Semi-Magnetic and Other 2-6 Semi-Conductor Super Lattices*
10:30 a.m.		**BREAK**

SCIENTIFIC SESSION II

10:40 a.m.	*Presiding:*	Professor Milton Slaughter Chairman, Department of Physics University of New Orleans
	Speaker:	Dr. Ronald Mallet University of Connecticut *Evaporating Black Holes in an Inflationary Universe*
11:25 a.m.	*Speaker:*	Professor Charles Brown Chairman, Department of Physics Clark-Atlanta University *Completely and Partially Polarized Signal Propogation in Single Mode Optical Fibers*

12:10 p.m.

LUNCHEON SESSION

Southern University Cotillion Ball Room

	Presiding:	Dr. Larry Madison Lawrence Livermore National Laboratory
	Speaker:	Dr. Charles McGruder Western Kentucky University *Is the Jet in Quasar 1038+064 Precessing?*

SCIENTIFIC SESSION III

2:00 p.m.	*Presiding:*	Professor Demetrius Venable Chairman, Department of Physics Hampton University
	Speaker:	Dr. James Evans Lawrence Livermore National Laboratory *Change, Challenge, and Opportunities*

2:30 p.m. **PANEL DISCUSSION**

Moderator: Professor Gabriel A. Oyibo
Aerospace Engineering Department
Polytechnic University of New York

Topic: Minority Under-Representation in
Science - A Search for Solutions

Panelists: Mr. Gerald Davis
HBCU Program Manager
Lawrence Livermore National Laboratory

Dr. Doyle Temple
Assistant Professor
Louisiana State University

Ms. April Richard
Senior Physics Student
Southern University

Mr. Albert Green
Graduate Student
Stanford University

FRIDAY, MARCH 23

SCIENTIFIC SESSION IV

9:00 a.m.	*Presiding:*	Professor Ronald Mickens Clark-Atlanta University
	Speaker:	Dr. Sekazi Mtingwa Argonne National Laboratory *Physics of the Anistropic Ferrite Wakefield Accelerator*
9:40 a.m.	*Speaker:*	Dr. Larry Madison Lawrence Livermore National Laboratory *Absolute Multilayer Characterization at High Spatial Resolution via Real Time Soft X-Ray Imaging*
10:30 a.m.		**BREAK**

SCIENTIFIC SESSION V

10:35 a.m.	*Presiding:*	Professor Harold Vincent Xavier University
	Speaker:	Professor Homer Neal Chairman, Department of Physics University of Michigan *Update on the Status of the Superconducting Supercollider (SSC) Laboratory*
11:10 a.m.	*Speaker:*	Dr. James King Jet Propulsion Laboratory *The Use of Charge Coupled Devices in Remote Sensing from Space*
12:00 p.m.		**LUNCHEON SESSION**
	Presiding:	Professor C. H. Yang Chairman, Department of Physics Southern University
	Speaker:	Dr. Sekazi Mtingwa Argonne National Laboratory *A Scientific Visit to the USSR*

Shabaka	Sababu	
Shepard	Keith	Howard University
Slaughter	Milton	University of New Orleans
Smith	Cecily	Norfolk State University
Smith	David	Jackson State University
Smith	Horace	Southern University
Smith	Margaret	Prairie View A&M University
Smith	William	Howard University
Snow	Nan	National Physical Science Consortium
Stallworth	Ed	Southern University
Stith	John	Virginia State University
Sulcer	Jarvis	Southern University
Sykes	Marvin	
Taylor	Charles	Norfolk State University
Teal	David	Tougaloo College
Thomas	Edwin	Prairie View A&M University
Thomas	Jeffrey	Norfolk State University
Thomas	Sean	Norfolk State University
Thomas	Stevie	Clark Atlanta University
Thompson III	Willie	University of Florida
Thorne	Shannon	Norfolk State University
Thornton	Tisha	Dillard University
Tsai	Stanley	Lincoln University
Turnbull	Hugo	Wayne State University
Turner	Matthew	Howard University
Venable	Demetrius	Hampton University
Vincent	Harold	Xavier University
Waddell	Emmanuel	Morehouse College
Wallace	Denesia	Southern University
Washington	Donna	Texas A&M University
Washington	Pamela	University of Chicago
Watson	Russal	Howard University
White	Calvin	Lincoln University
Williams	Barbara	
Williams	Cornelius	Michigan State University
Williams	James	University of Colorado at Boulder
Williams	Marianella	Southern University
Williams	Quinton	Jackson State University
Williams	Willie	Lincoln University
Wilson	Kevin	Norfolk State University
Wilson III	Walter	Crafton Hills College
Winbish	Phillip	Southern University
Woods	Talandia	Tougaloo College
Wright	Tara	Stillman College
Yang	Chia	Southern University
Yuh	Emmanuel	Wayne State University
Zeidman	Ben	Argonne National Lab.
Zhang	Jian	Southern University

Madison	Larry	Lawrence Livermore National Lab.
Major	Helen	Lincoln University
Mallett	Ronald	University of Connecticut
Martin	Julia	Southern University
Masterson	Merton	Tougaloo College
Mattix	Larry	Norfold State University
Mbonye	Manasse	
McGruder	Charles	Western Kentucky University
Melton	Jeffrey	Southern University
Mgonye	Manasee	Wayne State University
Michael	Jason	Howard University
Mickens	Ronald	Clark-Atlanta University
Miller	Tracy	
Mitchell	Sharanda	Howard University
Mixon	Melody	Clark-Atlanta University
Moore	Carlyle	Morehouse College
Morgan	Windsor	Penn State University
Morris	Rollin	
Mtingwa	Sekazi	Argonne National Lab.
Muhammed	Fuad	Clark-Atlanta University
Myers	Terry	Clark-Atlanta University
Ndow	Gabriel	Clark-Atlanta University
Neal	Homer	Stanford University
Neal	Homer	University of Michigan
Nelson	Danelle	Lincoln University
Niles	Julian	Clark-Atlanta University
Norman	Larry	Norfolk State University
Oxidine	Elias	Norfolk State University
Oyedeji	Kale	Morehouse College
Oyibo	Gabriel	Polytechnic University of New York
Parsons, Jr.	James	
Pase	Angela	Lincoln University
Pearson	Roderick	Jackson State University
Pearson	Stephen	Alabama A&M University
Penn	Kenneth	Southern University
Phillips	Alfred	IBM
Phillips	Damon	Morehouse College
Presley	John	Lincoln University
Pressley, Jr.	Henry	Benedict College
Rambabu	Bobba	
Ransom	Harrison	Norfolk State University
Redd	Richard	Southern University
Reed	Kennedy	Lawrence Livermore National Lab.
Reynolds	Lisa	Norfolk State University
Richard	April	Southern University
Richmond	Tracy	Howard University
Roberts	Lynn	Lincoln University
Rockward	Tommy	Southern University
Ruffin	Ineatha	

Hampton	Chenita	Southern University
Harris	James	Vanderbilt University
Harris	Patricia	Talladega College
Harris	Steven	Prairie View A&M University
Hart	Monica	Howard University
Hayes	Nancy	JPL-Voyager Spacecraft
Hayes	Nathan	Memphis State University
Hayes	Pervis	Southern University
Heard	Irvin	CUNY
Helzer	Shannon	Norfold State University
Henry	Lawrence	Wayne State University
Henry	Michael	University of Alabama
Hill	Dana	Morgan State University
Hogue	Kenith	Wayne State University
Holley II	Fredrick	Tougaloo College
Horne, Jr.	Rudy	University of Oklahoma
Huggins	Paul	
Hunter	Ivan	Southern University
Ibrahim	Mahdi	Clark-Atlanta University
Jackson	Shirley	AT&T Bell Laboratories
James	Floyd	Jackson State University
Johnson	Al	University of Georgia
Johnson	Andrea	Dillard University
Johnson	Joseph	CUNY
Johnson	Lewis	North Carolina State University
Jones	Alfred	Lincoln University
Jones	Angela	Stillman College
Jones	Charles	
Jones	Earline	
Jones	Gregory	Morgan State University
Jones	Steven	Southern University
King	James	JPL
King	Terez	Morgan State University
Lamb	Carolyn	Lincoln University
Lane	Vincent	University of Florida
Lars	Linda	University of Florida
Lawson	Charles	Prairie View A&M University
Lawson	Huey	Southern University
Ledbetter	Ezra	Hampton University
Lee	Eric	Texas A&M University
Lee	Patricia	Clark-Atlanta University
Lewis	Lonzy	Jackson State University
Liddell	Reginald	Jackson State University
London	Michael	Lincoln University
Long	Mervielle	Southern University
Lowe	Walter	AT&T Bell Laboratories

Carr	Jacqueline	Clark-Atlanta University
Carson	LaVonne	Lincoln University
Chotoo	Kancham	Howard University
Clark	Amelia	Norfolk State University
Clay	Alicia	Purdue University
Coakley	H. Mwalimu	UCLA
Coleman	Clarence	Norfolk State University
Coleman	Jewell	
Cooper	Crystal	Howard University
Crawley	Gerald	
Cunningham	Jevne	University of Michigan
Davenport	James	Virginia State University
Davis	David	Howard University
Davis	Gerald	Lawrence Livermore National Lab.
Davis	Jimmie	Morehouse College
Davis	Nicole	Jackson State University
Davis	Stanley	Catholic University
Delough	Carlos	Hampton University
Dhar	S.	Southern University
Doakes	Kelley	Prairie View A&M University
Dorsey	Fred	Stillman College
Drake	Carl	Jackson State University
Drakeford	Jerome	University of Nebraska
Dutchin	Gavin	MIT
Earls	Julian	NASA Lewis Research Center
Evans	Aaron	University of Michigan
Evans	Curtis	Clark-Atlanta University
Evans	James	Lawrence Livermore National Lab.
Evans	Kervin	Tougaloo College
Evans	William	Harvard University
Farrow	Todd	Lincoln University
Ferguson	Milton	Norfolk State University
Fields	Stephan	Southern University
Figueried	Lee	Superconducting Super Collider
Foster	John	Jackson State University
Gamble	Brian	North Carolina State University
Garcia	J.D.	University of Arizona
Garrett	Devonnja	Talladega College
Gates	Sylvester	University of Maryland
George	M. C.	Alabama A&M University
Glasgow	Victor	Howard University
Good	Sheryl	Clark Atlanta University
Gransberry	Lamonica	Southern University
Green	Albert	Stanford University
Greene	Rodney	University of Illinois
Griffin	Maurice	Southern University
Grimes	Kenneth	Boston University

List of Conference Participants

Agueman	Yaw	Prairie View A&M University
Allen	Donica	Hampton University
Allotey	Francis K.A.	Kumasi Ghana
Ammons	Edsel	University of Illinois
Anderson	Audrey	Lincoln University
Anderson	Charles	Dillard University
Ashley	Al	Stanford Linear Accelerator Center
Ayo	Dana	Southern University
Babbitt	Donald	UCLA
Bagayoko	Diola	Southern University
Ball	Eunice	Dillard University
Barnes	Gregory	Southern University
Barnes	Julius	Prairie View A&M University
Bartee, Jr.	Howard	Tougaloo College
Bell	Quincy	North Carolina A&T University
Bell	Stephen	Prairie View A&M University
Bethley	Charles	Southern University
Blaylock	Valena	Taledeaga College
Brackett	Latani	Norfolk State University
Brass	Eric	
Brewer	Gregory	Morehouse College
Brooks	Jerome	Norfolk State University
Brown	Charles	Clark-Atlanta University
Brown	Christopher	Norfolk State University
Brown	John	North Carolina A&T University
Brown	Nicole	Lincoln University
Brown	Stephen	
Brown	Terrence	Stillman College
Brown	Trenyaae	
Browne	Quentin	Stillman College
Brunson	Nisaa	Stillman College
Bryant	William	Alabama A&M University
Buck	Warren	Hampton University
Buckley	Jocelyn	Howard University
Bullock	S. Ray	Memphis State University
Burnett	Sanseeahray	Southern University
Butler	Malcolm	University of Florida

Students Sponsored by

NSBP and the Office of Naval Research

Donica Allen	Hampton University
Crystal Cooper	Howard University
Stanley Davis	Catholic University
Carlos Delock	Hampton University
Jerome Drakeford	Creighton University
Irvin I. Heard, Jr.	City University of New York
Paul M. Huggins, Jr.	Benedict College
Henry Pressley, Jr.	Benedict College
Cecily Smith	Hampton University

Students recommended by Prof. Joseph A. Johnson (City University of New York) and Dr. Kennedy Reed (Lawrence Livermore National Laboratory)

Speakers and Special Guests sponsored by Lawrence Livermore National Laboratory

Prof. F.K.A. Allotey
University of Science and Technology
Kamasi, Ghana, West Africa

Prof. Gabriel A. Oyibo
Polytechnic University of New York

Dr. Julian Earls
NASA Lewis Research Center

Dr. Charles H. McGruder III
Western Kentucky University

Dr. Ronald Mallett
University of Connecticut

Mr. James Evans
Lawrence Livermore National Laboratory

Dr. Larry Madison
Lawrence Livermore National Laboratory

Dr. Kennedy Reed
Lawrence Livermore National Laboratory

Dr. Manuel Perry
Lawrence Livermore National Laboratory

Mr. Gerald R. Davis
Lawrence Livermore National Laboratory

Speakers and special guests invited by Dr. Kennedy Reed

Norfolk State University

Students	Faculty
Amelia Clark	Dr. Larry Mattix
Shannon Thorne	Dr. Milton Ferguson
Lisa Reynolds	Mr. Harrison Ransom
Christopher Brown	Mr. Charles Taylor
Larry Norman	
Jeffrey Thomas	
Sean Thomas	
Jerome Brooks	
Elias Oxidine	
Kevin Wilson	

Prairie View A&M University

Students

Charles Lawson
Margaret Ann Smith
Julius Barnes
Edwin Thomas

Howard University

Students

Monica Hart
Jocelyn Buckley

Jackson State University

Students	Faculty
John Foster	Prof. Lonzy J. Lewis
Reginald Liddell	Prof. Carl T. Drake
Tracy Miller	Prof. Floyd James
Quinton Williams	
Roderick Pearson	
David Smith	
Nicole Davis	

Lincoln University

Students	Faculty
Danelle Nelson	Dr. John Presley
Todd Farrow	Dr. Lynn Roberts
Sharanda Mitchell	Dr. Willie Williams
Angela Page	Prof. Stanley Tsai
LaVonne Carson	Michael London
Alfred Jones	Mrs. Helen Major
Nicole Brown	
Carolyn Lamb	
Calvin White	
Audrey Anderson	

Morehouse College

Students	Faculty
Damon Phillips	Dr. Kali Oyedaji
Jimmie Davis	Dr. Carlise Moore
Gregory Brewer	
Emmanuel Waddell	

Students and Faculty Members sponsored by Lawrence Livermore National Laboratory

SCHOLARSHIPS

Alicia Clay	Purdue University
Wm. J. Evans	Harvard University
Albert Green	Stanford University
Homer Neal	Stanford University
Windsor Morgan	Pennsylvania State University

SPONSORSHIPS

Alabama A&M University

Students	Faculty
Marvin Sykes	Dr. M. C. George
Steven Pearson	
Michael Henry	
William Bryant	

Clark-Atlanta University

Students	Faculty
Terry Myers	Dr. Fuad Muhammad
Particia L. Lee	
Jacquelyn Carr	
Curtis Evans	
Julian Niles	
Sheryl Good	
Mahdi Ibraham	
Francis Nyandeh	
Gabriel Ndow	
Melody Mixon	

Scholarship students selected by Dr. Kennedy Reed
Sponsorship students selected by Mr. Gerald Davis and Dr. Kennedy Reed

SATURDAY, MARCH 24

10:00 a.m.		**WORKSHOP**
	Presiding:	Dr. Walter Lowe AT&T Bell Laboratory Chairman, American Physical Society Committee on Minorities in Physics
	Topic:	Funding Opportunities & Initiatives For Students and Practicing Scientists
	Panelists:	Ms. Nan Snow Executive Director National Physical Science Consortium (NPSC)
		Professor J. D. Garcia University of Arizona President of NPSC
		Dr. Benjamin Zeidman Argonne National Laboratory
		Professor Diola Bagayoko Southern University
12:00 p.m.		**ADJOURNMENT**

Program Committee

Dr. Kennedy Reed	Lawrence Livermore National Laboratory
Prof. Joseph A. Johnson III	The City College, City University of New York
Dr. Larry Madison	Lawrence Livermore National Laboratory

Organizing Committee

Prof. Diola Bagayoko	Southern University
Mr. Gerald Davis	Lawrence Livermore National Laboratory
Prof. Robert Ford	Southern University
Prof. Rose Glee	Southern University
Prof. Joseph A. Johnson III	The City College, City University of New York
Prof. Huey Lawson	Southern University
Dr. Kennedy Reed	Lawrence Livermore National Laboratory
Prof. Roena Wilford	Southern University
Prof. C. H. Yang	Southern University

SCIENTIFIC SESSION VI

1:30 p.m.	*Presiding:*	Mr. Gerald Davis HBCU Program Manager Lawrence Livermore National Laboratory
	Speaker:	Ms. Angela Page Lincoln University *Migdal-Kadanoff Study of Z_5 Symmetric Systems with Generalized Action - Part 1*
	Speaker:	Ms. Lavonne Carson Lincoln University *Migdal-Kadanoff Study of Z_5 Symmetric Systems with Generalized Action - Part 2*
	Speaker:	Ms. Nancy Hayes Jet Propulsion Laboratory *The Voyager Mission* *Exploration of the Solar System with Robotic Spacecraft*
2:10 p.m.	*Speaker:*	Dr. Julian Earls Associate Director NASA Lewis Research Center *Keynote Address*
3:05 p.m.		**BREAK**
3:20 p.m.		**BUSINESS MEETING**
	Presiding:	Joseph A. Johnson III The City College, City University of New York (CUNY) President, National Society of Black Physicists
6:00 p.m.		**RECEPTION**
		The Bellemont Hotel Sponsored by Southern University
7:00 p.m.		**BANQUET**
	Presiding:	Professor Joseph A. Johnson III CUNY
	Speaker:	Professor Francis A. K. Allotey University of Science and Technology Kumasi, Ghana, West Africa Chairman, African Association of Science